



VERSION TABLE

INDEX TO		multiply by
	amperes	1,000,000 (10^6)
	amperes	1,000 (10^3)
	s	0.000,000,001 (10^{-9})
	s	0.3937
Chapter	s	0.01 (10^{-2})
1. Direct-current	henrys	0.001 (10^{-3})
	enrys	0.000,001 (10^{-6})
2. Alternating-curr	microfarads	1.1124
	cles	0.001 (10^{-3})
3. Introduction to	cycles	0.000,001 (10^{-6})
	arads	1,000,000 (10^6)
4. Transmitting-ci	microfarads	1,000,000,000,000 (10^{12})
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	eters	1,000,000,000 (10^9)
5. Receiving-circu	henrys	1,000,000 (10^6)
	enrys	1,000 (10^3)
6. Electronic Powe		746
	eters	2.54
7. Antennas and V		10,000,000 (10^7)
		1,000 (10^3)
8. Frequency Mod	ycles	0.001 (10^{-3})
		1,000 (10^3)
9. Aviation Radio	power	1.34
	per second	1,000 (10^3)
10. Broadcast Stud	cles	1,000 (10^3)
		3.28
11. Broadcast Cont	hos	1,000,000 (10^6)
	es	0.000,001 (10^{-6})
12. Broadcast AM		0.000,001 (10^{-6})
	microfarads	1,000,000 (10^6)
13. Marine Radio		0.000,001 (10^{-6})
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	enrys	1,000 (10^3)
		0.000,001 (10^{-6})
15. Marine Automa		0.000,001 (10^{-6})
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16. Marine Radio		0.000,000,000,001 (10^{-12})
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17. Motors and Ge	es	0.001 (10^{-3})
	eters	1,000,000 (10^6)
18. Storage Batter		0.001 (10^{-3})
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Appendix (Useful T	ms	0.000,001 (10^{-6})
	ms	1,000,000 (10^6)
	volts	1,000,000 (10^6)
	olts	1,000 (10^3)
	atts	0.001 (10^{-3})
	watts	1,000,000 (10^6)
	atts	1,000 (10^3)

Practical Radio Communication

PRINCIPLES — SYSTEMS — EQUIPMENT — OPERATION

Including

Very High and Ultra-high Frequencies and Frequency Modulation

BY

signed
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SECOND EDITION

McGRAW-HILL BOOK COMPANY, INC.

NEW YORK AND LONDON

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UNIVERSITY OF MICHIGAN

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PREFACE TO THE SECOND EDITION

Rapid and extensive advances in the science of radio communication make this second edition necessary. Approximately two-thirds of the text is new. A noteworthy improvement has been made in chapter groupings; basic radio principles are now concentrated in the first eight chapters. Aviation radio, broadcasting, and marine radio follow in the order given. This arrangement will make the book easy for the student to use, for he will concentrate first on those chapters in which he is immediately interested, saving the remainder of the book for post-graduate study. The adaptability of the book to this latter purpose is attested to by its large distribution to employed radio operators who continue studying for self-improvement.

Important additions in this edition are Ohm's law problems and explanations, principles of high-efficiency radio-frequency amplifiers, receiver-circuit design, the cathode-ray oscilloscope, antenna arrays, ultra-high-frequency theory and practice, frequency modulation, aviation radio, latest broadcast equipment, and four complete chapters on marine radio, including automatic alarms and modern direction finders.

This second edition is also designed to satisfy the technical radio requirements of the National Association of Broadcasters' (NAB) *Two Suggested Intensive Radio Technician Training Courses in Fundamentals of Radio*. Each item listed in the outlines of the aforementioned courses will be found to be covered in this book and referred to in the *Index*. Students will find this book particularly valuable as a basic source of information underlying the questions and answers covered in its companion volume *Radio Operating Questions and Answers*. In addition this book will supply the advanced text material which many of the radio students of the above NAB courses will require upon completion of the fundamental courses.

The size of the book has been increased so that it is now approximately one-fifth larger than before with over 200 new illustrations. Particular care has been taken to make all circuit diagrams clear and understandable.

The authors gratefully acknowledge the cooperation given to them in the preparation of this edition by many individuals and organizations, and by those companies whose names appear in the credit line under many of the illustrations, to whom they applied for specific information. In particular, they wish to acknowledge the help received from J. S. Peterson, who, out of his wide experience in this phase of radio, wrote the chapter on Frequency Modulation. They are indebted to Paul von Kunits for

his able assistance in revising the chapters on broadcast-studio and control-room equipment. They are also very grateful for the technical information on marine radio equipment supplied by the Radiomarine Corporation of America and the Mackay Radio & Telegraph Company, and for the technical information on aviation radio and broadcast transmitters supplied by the Western Electric Company.

They wish also to express their appreciation to Walter N. Dean, M.S. in E.E., Columbia 1941, for his aid in reading proofs of Chaps. 1 to 8 inclusive, and 17, and for his constructive criticism of these chapters.

To those who cooperated in the preparation of this book and to the students and radiomen who will use it, this second edition is dedicated with the hope that it will continue to be as useful in the future as it has been in the past.

THE AUTHORS.

NEW YORK, N. Y.,
January 1943.

PREFACE TO THE FIRST EDITION

The modern radio communication center with its numerous transmitters and associated equipment is a far cry from the isolated radio station of a decade or so ago. The highly developed stations of the present day demand of their operating personnel a skill which is closely akin to radio engineering. Broadcasting and its consequent effect on all radio are largely responsible for this. Broadcasting gave a spurt to radio unequalled in the annals of any other scientific development. Apparatus was hurriedly built and the erection of stations rushed. The technical aspects of radio were in a constant upheaval, apparatus, methods, and even systems changing from month to month. But the initial confusion is now over; radio has found its stride, so to speak, and its technique is quite settled. Radio evolution in the future holds promise of being less spasmodic.

The situation thus pictured has been recognized by the government in the establishment of the Federal Communications Commission with a special division charged with the establishment of technical standards to which all licensed radio operators must conform. These standards are high and keep pace with scientific radio development. But there are other even higher standards up to which the technical radio operator-technician must measure. We refer to the standards set up by employers of technical radio personnel. These employers have found it good business to employ only thoroughly qualified men. It follows, therefore, that technical radio education must fill this demand.

It was to meet the expanded scope of technical radio requirements that this book was planned. We believe that our objective of providing within one volume most of the technical information required by the practical radio operator-technician has been achieved. The original manuscript would have made a book almost 50 per cent larger than the present volume, with a consequent increase in price. Hence, in order to keep the size of the book within reasonable limits, many sections were condensed. Wherever a diagram in the practical sections told the story, a word-for-word explanation was omitted. What the reader does not find in the text, therefore, he will usually learn from the diagram. As far as possible, items on the diagrams have been labeled. This has been done to aid the reader and instructor in referring to these specific items, even though a list of parts may not accompany the diagram.

The book is divided roughly into two parts: Principles and Practice. The first six chapters are given over to principles and the remaining nine

chapters to practice. High-grade technical skill is always founded on a sound basis of fundamental principles. It has been our purpose, therefore, to go into these principles extensively, delving deeply into alternating current, which plays an important part in modern radio. It is on the assumption that these principles have already been mastered that the practical sections of the book have been written. In fact, it is necessary that these principles be understood before the practical sections, beginning with Chap. VII, can be read intelligently.

Throughout the book, wherever current flow is treated, the electron viewpoint (negative to positive) has been adhered to. Indications are that the general trend in radio technical circles is in this direction, rather than in the direction of a blind acceptance of the conventional (positive to negative) direction law expounded in the majority of texts on electricity.

Particular attention has been given to broadcasting, and much of the material included on this subject appears here for the first time in a radio textbook. The practical description of the Western Electric broadcast transmitter is written on a basis of wide operating experience with this equipment. The treatment as here given is not a mere digest of instruction-book material; and the diagrams accompanying the text were especially prepared and simplified for our purpose.

Broadcast men will also find the chapters on Studio Acoustics and Apparatus, Control-room Equipment and Operation, and Antennas to be of great value for the ordinarily inaccessible information which they contain.

Police operators will find much of interest in the broadcast sections and, in addition, in the sections on ultra-short-wave equipments, which are now extensively used for police communications.

Aviation radio is treated from the radio-telegraphic, as well as from the radio-telephonic, angle. Modern aircraft transmitters, receivers, and direction-finding equipment together with the testing and maintenance of this apparatus are included.

Nowhere is radio more important than in its marine applications; and it is with this in mind that the sections dealing with marine radio have been written. In addition to the conventional medium-frequency equipment, high-frequency transmitters and receivers have been fully illustrated and explained. Low-power transmitters such as are used by the Coast Guard have also been included. Marine direction finders and the principles underlying all such equipment are completely covered in a special chapter.

The last three chapters of the book are given over to a thorough treatment of power-supply apparatus including rectifiers, generators, and batteries, and their associated equipment. By placing this material at the end of the book we have saved the reader the necessity of tediously

completing these power chapters before getting on to the more interesting study of radio circuits. We feel that this approach to the subject, although a new one, offers distinct pedagogical advantages.

Lack of space did not permit a discussion of the nearly obsolete spark and arc transmitters or of radio laws. Those readers who wish information on these old type transmitters will find them adequately described in the authors' "Practical Radio Telegraphy," the predecessor to this volume. Radio laws have been fully treated in the companion book to this volume, the authors' "Radio Operating Questions and Answers," and in inexpensive government publications.

In short, this book covers the requirements for *all classes* of radio operators' license examinations, treats long, medium, short, and ultra-short-wave radio, includes *all classes* of radio stations, and, in general, is a complete text on the practical radio communication based on a theoretical introduction.

THE AUTHORS.

NEW YORK, N. Y.,
June, 1935.

CONTENTS

	PAGE
PREFACE TO THE SECOND EDITION.	v
PREFACE TO THE FIRST EDITION.	vii
ABBREVIATIONS.	xix
RADIO SYMBOLS	xxiv

CHAPTER 1

DIRECT-CURRENT ELECTRICITY AND MAGNETISM.	1
--	---

PART I. ELEMENTARY ELECTRICITY: 1.1. Electric Charges and Forces; 1.2. Protons and Electrons; 1.3. Potential; 1.4. Free Electrons in Solid Conductors; 1.5. Electric Current; 1.6. Electromotive Force; 1.7. Current Strength and Quantity; 1.8. Electrical Resistance and Conductivity of Materials; 1.9. Ohm's Law; 1.10. Simple Electric Circuits; 1.11. The Shunt Law; 1.12. Kirchhoff's Laws; 1.13. Conductance; 1.14. Energy, Force, Work, and Power; 1.15. Electrical Power; 1.16. Load Matching; 1.17. E.M.F. Produced by Chemical Action; 1.18. Directions of Current Flow; 1.19. Local Action; 1.20. The Voltage of a Cell; 1.21. The Capacity of a Cell; 1.22. Connection Methods; 1.23. Internal Resistance of a Cell; 1.24. The Telephone Receiver and Transmitter.

PART II. MAGNETISM AND ELECTROMAGNETISM: 1.25. Natural and Artificial Magnets; 1.26. Poles of a Magnet; 1.27. Magnetic Fields; 1.28. Magnetic Transparency and Leakage; 1.29. Theory of Magnetism; 1.30. Magnetic Variables; 1.31. Purpose of Pole Pieces; 1.32. Magnetostriction Effect; 1.33. Fields around Conductors; 1.34. Induced Currents; 1.35. Production of E.M.F. by Field Cutting Conductor.

PART III. THE MAGNETIC CIRCUIT: 1.36. The Magnetic Circuit; 1.37. Ohm's Law Equivalent for Magnetic Circuits; 1.38. Magnetic-circuit Computations; 1.39. Hysteresis.

CHAPTER 2

ALTERNATING-CURRENT ELECTRICITY	60
--	----

PART I. ALTERNATING-CURRENT GENERATION AND TRANSFORMATION: 2.1. The Alternator Principle; 2.2. Principles of the Transformer.

PART II. INDUCTANCE: 2.3. Induction; 2.4. Self-induction; 2.5. Mutual Induction; 2.6. Inductance Measurements; 2.7. Practical Inductance Formulas; 2.8. Mutual Inductance Measurements.

PART III. CAPACITY: 2.9. The Electrostatic Field and the Condenser; 2.10. Capacity of a Condenser; 2.11. Specific Inductive Capacity; 2.12. Energy in a Charged Condenser; 2.13. Capacity of Condensers in Parallel; 2.14. Capacity of Condensers in Series; 2.15. Capacity Measurements.

PART IV. ELEMENTS OF ALTERNATING-CURRENT ENGINEERING: 2.16. Construction of a Sine Wave; **2.17.** Frequency and E.M.F. Formulas; **2.18.** Effective Voltage and Current; **2.19.** Effect of Resistance on Phase Relations; **2.20.** Effect of Inductance on Phase Relations; **2.21.** Effect of Capacity on Phase Relations; **2.22.** Power Factor; **2.23.** Ohm's Law Adapted to Alternating-current Circuits; **2.24.** Series Circuit Analysis; **2.25.** Parallel Circuit Analysis; **2.26.** Series Resonance; **2.27.** Parallel Resonance; **2.28.** Power Relations in Alternating-current Circuits; **2.29.** Kilovolt-amperes; **2.30.** Polyphase Alternating-current Circuits; **2.31.** Power in a Three-phase System.

CHAPTER 3

INTRODUCTION TO RADIO TUBES AND CIRCUITS. 105

PART I. VACUUM-TUBE CHARACTERISTICS: 3.1. The Filament; **3.2.** Effect of Plate Potential on Plate Current; **3.3.** Effect of Filament Current on Plate Current; **3.4.** The Control Grid; **3.5.** Vacuum-tube Characteristics; **3.6.** Amplification Factor; **3.7.** Plate Resistance; **3.8.** Transconductance; **3.9.** The Alternating-current-operated Vacuum Tube.

PART II. THE RADIO-FREQUENCY AMPLIFIER: 3.10. General Amplifier Considerations; **3.11.** The Class A Amplifier; **3.12.** The Class AB Amplifier; **3.13.** Class B and Class C Amplifiers; **3.14.** Balance Circuits; **3.15.** Neutralization of a Transmitting Circuit; **3.16.** Radio-frequency Shielding; **3.17.** Inductance and Capacitive Changes with Shielding; **3.18.** Grid-biasing Methods; **3.19.** Radio-frequency Chokes.

PART III. VACUUM-TUBE OSCILLATORS: 3.20. General Oscillator Considerations; **3.21.** Fundamental Oscillator; **3.22.** The Hartley Oscillator; **3.23.** The Colpitts Oscillator; **3.24.** The Push-pull Oscillator; **3.25.** Conventional Electron-coupled Oscillator; **3.26.** The Dynatron Oscillator.

PART IV. RADIO AND POWER-CIRCUIT COMPONENTS: 3.27. Radio Circuit Components.

CHAPTER 4

TRANSMITTING-CIRCUIT PRINCIPLES 148

PART I. CONVENTIONAL CIRCUITS: 4.1. General Transmitting Considerations; **4.2.** Classification of the Radio Spectrum; **4.3.** The Oscillator as a Transmitter; **4.4.** The Oscillator-amplifier Transmitter; **4.5.** The Crystal-controlled Transmitter; **4.6.** The Practical Oscillator; **4.7.** The Mechanical Resonator; **4.8.** The Crystal Resonator; **4.9.** The Temperature-control Chamber; **4.10.** The Buffer Amplifier; **4.11.** The Second Amplifier; **4.12.** Harmonic Producers; Frequency Multipliers; **4.13.** Modulation; **4.14.** Modulation Percentage; **4.15.** Carrier and Side-band Relations; **4.16.** Modulation Methods; **4.17.** The Modulated Amplifier—Push-pull System; **4.18.** The Heising Modulating Systems; **4.19.** The Output Impedance of the Modulated Amplifier; **4.20.** The First and Second Power Amplifiers; **4.21.** Power-amplifier Grid Excitation; **4.22.** High-efficiency (Doherty) Power Amplifier; **4.23.** The Audio Monitor; **4.24.** The Frequency Monitor; **4.25.** Antenna Coupling Circuits; **4.26.** Meters; **4.27.** The Power Supply; **4.28.** Harmonics and Their Causes; **4.29.** The Suppression of Harmonics; **4.30.** Parasitic Oscillations.

PART II. ULTRA-HIGH-FREQUENCY CIRCUITS: 4.31. Ultra-high-frequency Systems; **4.32.** Ultra-high-frequency Oscillators; **4.33.** Modulation of Ultra-high Frequencies; **4.34.** Ultra-high-frequency Transmitters.

CHAPTER 5

RECEIVING-CIRCUIT PRINCIPLES. 203

5.1. General Receiving Considerations.

PART I. MULTIGRID TUBES, DETECTOR, AND AUDIO AMPLIFIER: 5.2. The Screen-grid Tube; 5.3. The Pentode Tube; 5.4. Beam Power Tubes; 5.5. The Vacuum-tube Detector; 5.6. Plate Detection; 5.7. Grid Detection; 5.8. Power Detection; 5.9. Grid-leak versus Power Detection; 5.10. The Vacuum-tube Amplifier; 5.11. Amplifier Distortion; 5.12. Power Amplification; 5.13. Push-pull Amplification; 5.14. Grid and Plate Filtration; 5.15. The Diode Detector; 5.16. The Automatic Volume Control; 5.17. Noise-suppression Circuit.

PART II. THEORY AND APPLICATION OF TUNED CIRCUITS: 5.18. General Circuit Considerations; 5.19. Simple Analysis of the Tuned Circuit; 5.20. Filter Circuits; 5.21. Isolation and Band-pass Circuits; 5.22. Rejector or Trap Circuits; 5.23. Regenerative Receiver; 5.24. Superregenerative Receiver; 5.25. Superheterodyne Receiver; 5.26. The Single-signal Receiver; 5.27. General Communications Receiver; 5.28. Ultra-short-wave Receivers.

PART III. RADIO-FREQUENCY-VOLTAGE AMPLIFIERS: 5.29. Radio-frequency-voltage Amplifiers.

PART IV. TESTING AND FREQUENCY MEASUREMENTS: 5.30. The Cathode-ray Tube; 5.31. Heterodyne Frequency Meter.

PART V. LOUD-SPEAKERS: 5.32. Loud-speakers

CHAPTER 6

ELECTRONIC POWER SUPPLIES. 293

PART I. THE POWER TRANSFORMER: 6.1. General Transformer Considerations; 6.2. Voltage-regulating Transformers; 6.3. Electrostatically Shielded Transformers; 6.4. Protective Devices.

PART II. THE RECTIFIER: 6.5. The Function of the Rectifier; 6.6. The High-vacuum Rectifier Tube; 6.7. The Mercury-vapor Rectifier Tube; 6.8. Inverse-peak Voltage; 6.9. Rectifier Circuits Classified; 6.10. Single-phase Rectifier Circuits; 6.11. Bridge-rectifier Circuit; 6.12. Voltage-doubler Rectifier; 6.13. Three-phase Rectifiers; 6.14. Junction Rectifiers.

PART III. THE RIPPLE FILTER: 6.15. Function of Ripple Filter; 6.16. The Action of Filter Condensers; 6.17. Paper Filter Condensers; 6.18. Electrolytic Filter Condensers; 6.19. The Action of the Choke Coil; 6.20. The First Choke Coil; 6.21. Equalizing and Bleeder Resistance; 6.22. Voltage Dividers.

PART IV. GENERAL RECTIFIER CONSIDERATIONS: 6.23. Ripple Frequency; 6.24. Losses in Rectifier Apparatus; 6.25. Typical Rectifier and Filter Systems; 6.26. Plate Fuses; 6.27. Rectifier Troubles.

PART V. ELECTRICAL INDICATING INSTRUMENTS: 6.28. Voltmeter for Continuous E.M.F.; 6.29. Ammeter for Direct Current; 6.30. Voltmeter for Alternating E.M.F.; 6.31. Ammeters for Alternating Current; 6.32. Thermal Ammeters; 6.33. Wattmeters; 6.34. Frequency Indicators; 6.35. The Ohmmeter.

CHAPTER 7

ANTENNAS AND WAVE PROPAGATION. 343

PART I. ELEMENTS OF RADIATION: 7.1. The Radiation Field; 7.2. Sky and Ground Waves; 7.3. Skip Distance; 7.4. Field Intensity.

PART II. ANTENNA SYSTEMS: 7.5. Short-wave Antennas; 7.6. Directive Antennas; 7.7. Feeding the Antenna; 7.8. Construction of Short-wave Antennas; 7.9. Ultra-high-frequency Antennas; 7.10. Principles of Operation and Design of Beam Antennas; 7.11. Ground Connection and Counterpoise; 7.12. Receiving Antenna; 7.13. Loop Antenna as Used for Directional Reception; 7.14. Minimizing the Error; 7.15. Effect of Frequency on Deviation; 7.16. Determining Sense of Direction; 7.17. The Bellini-Tosi System; 7.18. The Adcock Aerial for Directional Reception.

PART III. ANTENNA MEASUREMENTS: 7.19. Measuring Antenna Resistance; 7.20. Measuring Antenna Impedance; 7.21. Calculation of Antenna λ and R .

PART IV. EXTERNAL FACTORS AFFECTING RADIO COMMUNICATION: 7.22. Variable Factors Affecting Radio.

CHAPTER 8

FREQUENCY MODULATION. 388

PART I. THE TRANSMISSION OF FM WAVES: 8.1. FM Compared with AM; 8.2. Interchannel Interference; 8.3. Theory of FM; 8.4. Systems of FM; 8.5. The Armstrong Method; 8.6. Other Systems of FM; 8.7. The Western Electric 503A-1 FM Transmitter; 8.8. Practical Considerations of FM; 8.9. Propagation of FM Waves; 8.10. Polarization; 8.11. Transmitting Antennas for Use in the FM Band.

PART II. THE RECEPTION OF FREQUENCY-MODULATED SIGNALS: 8.12. The FM Receiver Compared with the AM Receiver; 8.13. The Limiter; 8.14. The Discriminator; 8.15. Radio-frequency Circuits in FM Receivers; 8.16. Servicing FM Receivers; 8.17. FM Receiving Antennas.

CHAPTER 9

AVIATION RADIO COMMUNICATION 430

PART I. TRANSMITTERS: 9.1. Multi-frequency Ground-station Transmitter; 9.2. Converting a Phone Transmitter for CW; 9.3. Transport Aircraft Transmitter; 9.4. Maritime Aircraft Radiotelegraph Transmitter.

PART II. RECEIVERS: 9.5. Transport Aircraft Communications Receiver; 9.6. Radio Beacon and General Purpose Receiver; 9.7. Marker Beacon Ultra-high-frequency Receiver; 9.8. Aircraft Antennas; 9.9. Aircraft Shielding and Bonding.

PART III. RADIO AIDS TO AVIGATION: 9.10. Action of Loop Transmitting Antennas; 9.11. Transmission-line (T-L) Antenna System; 9.12. Radio Beacon-signal Methods; 9.13. Marker Beacons; 9.14. The Single-loop Direction Finder; 9.15. The Sperry Automatic Radio Direction Finder.

CHAPTER 10

BROADCAST STUDIO. 500

PART I. STUDIO ACOUSTICS: 10.1. Distortion; 10.2. Reverberation; 10.3. Standard Practice Broadcast Studios; 10.4. Production and Microphone Placement; 10.5. Sound; 10.6. Use of Logarithms; 10.7. The Decibel.

PART II. MICROPHONES: 10.8. Microphones—General Considerations; 10.9. Carbon Microphone; 10.10. Condenser Microphone; 10.11. Dynamic Microphone; 10.12. Velocity or Ribbon Microphone; 10.13. Crystal Micro-

phone; 10.14. Directional Microphones; 10.15. Lapel Microphone; 10.16. Parabolic Microphone Receiver-reflectors; 10.17. Machine-gun Microphone.

PART III. ELECTRICAL TRANSCRIPTION APPARATUS: 10.18. Recordings; 10.19. Pickup Heads; 10.20. Pickup Equalization for Different Systems of Recording; 10.21. Expansion Systems; 10.22. Instantaneous Recording.

CHAPTER 11

BROADCAST CONTROL ROOM. 542

PART I. TRANSMISSION SET-UP: 11.1. Control-room Requirements; 11.2. Control-room Equipment.

PART II. MIXING EQUIPMENT: 11.3. General Requirements and Types of Mixers; 11.4. Stray Fields and Noises; 11.5. Insertion Loss; 11.6. Adjunct (NEMO) and Pickup Mixing.

PART III. AMPLIFIER CONSIDERATIONS: 11.7. Special Precautions against Disturbances; 11.8. Harmonic and Amplitude Distortion; 11.9. Advantages of Low-gain Amplifiers; 11.10. Types of Broadcast Amplifiers; 11.11. Plate and Grid Filtering; 11.12. The Main Gain Control; 11.13. Jack Circuits; 11.14. Reducing Hum Level; 11.15. General Considerations.

PART IV. PROGRAM TRANSMISSION: 11.16. Speech-input Equipment; 11.17. Remote-control Equipment; 11.18. Monitor Amplifiers; 11.19. Volume Indicators; 11.20. Equalizers and Equalizing; 11.21. Frequency Runs; 11.22. Attenuation Networks.

CHAPTER 12

BROADCAST AM TRANSMITTERS. 592

PART I. BROADCAST TRANSMITTERS: 12.1. The Broadcast Station; 12.2. Definition and Rating of the Transmitter; 12.3. The Operating Power; 12.4. Frequency Control; 12.5. Western Electric 1-kw. Broadcast Transmitter; 12.6. Relay Operation; 12.7. Western Electric 5-kw. Broadcast Transmitter; 12.8. The Frequency Monitor; 12.9. Modulation Measurements.

PART II. BROADCAST ANTENNAS: 12.10. Broadcast-transmitting Antennas; 12.11. Broadcast Transmission-line Coupling Circuits; 12.12. Application of the Antenna-coupling Unit; 12.13. Phase Monitors; 12.14. Antenna-resistance Measurement.

CHAPTER 13

MARINE RADIO TRANSMITTERS. 648

13.1. Radio Transmitters for Marine Use; 13.2. Keying Systems; 13.3. Production of A2 Emission; 13.4. Medium-frequency Transmitters; 13.5. Emergency Transmitter; 13.6. Lifeboat Radio Equipment; 13.7. High-frequency Radiotelegraph Transmitters; 13.8. Coastal-harbor Radiotelephone Equipment; 13.9. A Complete Ship-radio Station; 13.10. Transmitter Care and Maintenance; 13.11. Transmitter Troubles; 13.12. Ship Antennas; 13.13. Coast Stations.

CHAPTER 14

MARINE RADIO RECEIVERS. 722

14.1. Marine Receivers; 14.2. Audio-amplifier Response Characteristics; 14.3. Audio-Amplifier Troubles; 14.4. Power Supplies for Receivers; 14.5.

Protective Devices; **14.6.** Multiple Reception; **14.7.** Common Receiver Troubles Summarized; **14.8.** Main Receivers; **14.9.** Emergency Receivers; **14.10.** High-frequency Receivers; **14.11.** Filament Battery Charges; **14.12.** Crystal-detector Receivers; **14.13.** Marine Radio Accessories.

CHAPTER 15

MARINE AUTOMATIC RADIO ALARMS 754

15.1. Approved Auto Alarms.

CHAPTER 16

MARINE RADIO DIRECTION FINDERS 780

16.1. Applications of the Radio Direction Finder; **16.2.** Elements of Direction-finder Apparatus; **16.3.** Ground and Shielding; **16.4.** Signal Indication; **16.5.** Reducing Deviation; **16.6.** Commercial D/F Models; **16.7.** Marine Aircraft Direction Finders; **16.8.** Calibration; **16.9.** Operation; **16.10.** Fixing the Position; **16.11.** Maintenance; **16.12.** Troubles and Remedies.

CHAPTER 17

MOTORS AND GENERATORS 818

PART I. GENERATORS: **17.1.** Types of Alternators; **17.2.** Voltage Control on Alternators; **17.3.** Direct-current Generators; **17.4.** Commutation; **17.5.** Commutator Sparking; **17.6.** Commutating Poles; **17.7.** Compensating-field Windings; **17.8.** Double-commutator Generators; **17.9.** The Drum Armature; **17.10.** Armature Cores; **17.11.** Field Excitation; **17.12.** Brushes; **17.13.** Voltage Control on Direct-current Generators; **17.14.** Uses of Various Types of Generators; **17.15.** Regulation.

PART II. MOTORS: **17.16.** The Construction Principles of the Direct-current Motor; **17.17.** The Function of the Motor Commutator; **17.18.** Counter Electromotive Force: Torque; **17.19.** Types of Direct-current Motors; **17.20.** Alternating-current Motors.

PART III. MOTOR STARTING, CONTROL, AND OPERATION: **17.21.** Hand-starting Boxes; **17.22.** Automatic Starters for Direct-current Motors; **17.23.** Starting Induction Motors; **17.24.** Manual Speed Control; **17.25.** The Centrifugal Speed Regulator; **17.26.** Operation of Motors.

PART IV. MOTOR GENERATORS AND POWER-CONTROL APPARATUS: **17.27.** Advantages and Disadvantages of Motor Generator; **17.28.** The Dynamotor; **17.29.** The Converter; **17.30.** Double-current Generators; **17.31.** General Maintenance; **17.32.** Brush Troubles; **17.33.** Bearings; **17.34.** Trouble Shooting; **17.35.** Protective and Control Devices; **17.36.** Generator-ripple Reduction; **17.37.** Generator-ripple Filters.

CHAPTER 18

STORAGE BATTERIES 863

18.1. General Battery Considerations.

PART I. THE LEAD-ACID BATTERY: **18.2.** The Lead-acid Cell; **18.3.** Positive Plates; **18.4.** Negative Plates; **18.5.** The Active Material; **18.6.** The Electrolyte; **18.7.** Construction of Cells; **18.8.** Chemical Action in a Lead Cell; **18.9.** Specific Gravity and the Hydrometer; **18.10.** The Voltage of the Lead Cell; **18.11.** Discharge Rates and Limits; **18.12.** Charging and Charging

Rates; **18.13.** Charging Requirements; **18.14.** Charging Methods; **18.15.** Effect of Temperature on Operation; **18.16.** Gas and Ventilation; **18.17.** Effect of Wrong Polarity; **18.18.** Sulphation and Remedies; **18.19.** Care and Operation of Lead Cells; **18.20.** Troubles and Their Remedies.

PART II. THE NICKEL-IRON-ALKALINE BATTERY: **18.21.** The Nickel-Iron-Alkaline Cell; **18.22.** Care and Management; **18.23.** The Chemical Reaction in an Edison Cell; **18.24.** Charging; **18.25.** The State of Charge of an Edison Battery; **18.26.** Ventilation; **18.27.** Capacity; **18.28.** Summary of Data on Lead and Edison Cells.

PART III. STORAGE BATTERY SWITCHBOARDS AND CHARGERS: **18.29.** The Exide Switchboard; **18.30.** The Edison Battery Switchboard; **18.31.** Charging Panel for Receiver Batteries; **18.32.** Lifeboat Panel; **18.33.** Ampere-hour Meters; **18.34.** Reverse-current Relay; **18.35.** The Tungar Battery Charger.

APPENDIX

USEFUL TECHNICAL AND OPERATING INFORMATION

TABLE A.—WAVE-LENGTH-FREQUENCY CONVERSION TABLE.	907
TABLE B.—RELATION OF WAVE LENGTH (λ), FREQUENCY (f), $2\pi f = (\omega)$, AND $L \times C$	908
THREE-PLACE LOGARITHMIC TABLES.	911
INDEX.	915

ABBREVIATIONS

Note: Where a single symbol is given more than one meaning in this list, the application in a particular instance is obvious from the context of the text.

- A = voltage amplification or gain.
- A = area or cross section; amperes.
- a.c. = alternating current; in tables and lists = A.-C.
- ACW = attenuated continuous wave(s).
- ACCW = continuous waves generated by an alternating-current plate supply (ACW).
- a.f. = audio frequency; in lists and tabular matter = A.-F.
- AM = amplitude modulation
- amp. = ampere.
- av. = average.
- ma. = milliamperes.
- AVC = automatic volume control.
- B, b = susceptance.
- B = lines per square inch.
- $\mathfrak{B}$ = flux density in gaussses per square centimeter.
- C, c = capacity (farads).
- c.g.s. = centimeter-gram-second (absolute) system.
- cm. = centimeter.
- cond. = condenser.
- $\cos \phi$ = power factor $\frac{R}{Z}$; in text line R/Z .
- CW = continuous waves (unmodulated).
- d = distance; diameter; difference.
- db = decibel.
- d.c. = direct current.
- D/F = direction finder (radio).
- E = effective electromotive force; electrical pressure; volts.
- e.m.f. = electromotive force.
- e = instantaneous e.m.f.
- E, ϵ = electric-field intensity.
- $\vec{E}$ = vector e.m.f.
- E_A = maximum or resultant e.m.f.
- $\vec{E}_A$ = maximum or resultant vector e.m.f.
- E_c = grid-biasing voltage.
- E_{cn}, e_{cn} = counter e.m.f.
- E_g = grid-signal voltage swing.
- E.M.F., e.m.f. = electromotive force.
- E_0 = r.m.s. vector. $\left(\frac{E_A}{\sqrt{2}} \right)$
- E_p = vacuum-tube plate voltage.
- F = force (magnetomotive force in gilberts); filament; modulation factor.
- f = frequency, cycles per second; filament; farad.
- f_c = cut-off frequency.

- fl = full load.
 FM = frequency modulation.
 G, g = conductance; vacuum-tube grid.
 gal. = gallon(s).
 G_m = mutual conductance (micromhos).
 h = height.
 h. = henry.
 H = ampere turns.
 $\mathcal{H}$ = hysteresis; gilberts per centimeter.
 H = magnetic-field intensity; harmonic (pad type).
 H_2 = second harmonic (H_3 = third harmonic, etc.).
 HF = high frequency.
 I = effective current flow; strength of flow.
 i = instantaneous current.
 I_p = plate current.
 ICW = interrupted continuous waves.
 IF = intermediate frequency.
 $j = \sqrt{-1}$ (operating vector).
 K = numerical constant; dielectric constant.
 k = coupling coefficient.
 kc./s. = kilocycles.
 KVA., kva. = kilovolt-amperes ($E \times I \times 1,000$).
 KW, kw. = kilowatt ($E \times I \times \cos \phi \times 1,000$).
 L = inductance.
 l = length.
 LF = low frequency.
 log = logarithm.
 M = modulation percentage; meter (indicator).
 M = mutual inductance; mutual coupling.
 m. = meter (39.37 in.); modulation factor.
 MA = milliammeter.
 ma. = milliamperes.
 mc. or mc./s. = megacycle.
 MCW = modulated continuous waves.
 MF = medium frequency.
 mf., mfd. = microfarad.
 mmf. = micro-microfarad.
 m.m.f. = magnetomotive force.
 mh. = millihenry.
 $\mu h.$ = microhenry.
 $Mu = (\mu)$ = amplification factor or constant.
 M. O. = master oscillator.
 m.p. = maximum peak.
 M.O.P.A. = master-oscillator power amplifier.
 N = total number of turns; turns ratio; number of field poles.
 mv./m. = millivolts per meter.
 m.p.h. = miles per hour.
 mw. = milliwatts.
 n = number of turns.
 nl = no load.
 NEMO = pick-up equipment remote from main-studio control room.
 Osc. = oscillator.
 P = active electrical power (watts), $E \times I$; vacuum-tube plate.

- P.A. = power amplifier.
P, p = primary.
p = instantaneous power.
P.D. = potential difference (volts).
 p.f. = power factor.
Q = efficiency of a coil.
Q, q = quantity of electricity in coulombs or ampere-hours.
QAVC = noise suppression control.
R, r = resistance (ohms); radius.
R = reluctance.
R_o = resistance of output load or circuit.
R_p = vacuum-tube alternating-current plate resistance.
RCA = Radio Corporation of America, Inc.
R.F., r.f. = radio frequency.
RFA = radio-frequency ammeter.
R.M.C.A. = Radiomarine Corporation of America, Inc.
r.m.s. = root mean square.
r.p.m. = revolutions per minute.
r.p.s. = revolutions per second.
S, s = secondary; switch.
Sg, sg = screen grid.
SHF = super-high frequency.
Sw. = switch.
T, t = time in seconds.
T-L = transmission line.
UHF = ultra-high frequency.
V = vacuum tube.
v = velocity.
VA, va. = volts $\times$ amperes.
VHF = very-high frequency.
VI = volume indicator.
VLF = very low frequency.
VM, vm. = voltmeter.
VU = volume unit (same as *db*).
W = average electrical energy in joules or watt-hours ($E \times I \times t$).
W = watts.
W.E. = Western Electric Co.
w = instantaneous energy.
X = reactance (reactive ohms).
X_C = capacitive reactance (ohms).
X_L = inductive reactance (ohms).
X_M = mutual reactance (ohms).
Y, y = admittance.
Z = impedance (combined *R* and *X* in ohms).
 $|Z|$ = impedance magnitude (absolute value of).
Z_i = impedance of input load or circuit.
Z_o = impedance of output load or circuit.

SUBSCRIPT LETTERS

- A* = applied.
a = antenna.
a.c. = alternating current.
av = average.

eff = effective value.
 fl = full load.
 m = maximum value.
 max = maximum value.
 min = minimum value.
 $ma.$ = milliamperes.
 $\mu v./m.$ = microvolt per meter.
 $mv./m.$ = millivolt per meter.
 nl = no load.
 i = input.
 o = output.
 P, p = primary.
 $p.r.$ = parallel-resonant.
 S, s = secondary.
 $s.r.$ = series-resonant.
 $r.m.s.$ = root mean square.

SPECIAL SIGNS

θ = phase angle.
 λ = wave length.
 μ = permeability; amplification factor.
 μf = microfarad.
 $\mu\mu f$ = micro-microfarad.
 μh = microhenry.
 $\mu v.$ = microvolts.
 $\mu v./m.$ = microvolts per meter.
 $\mu\mu w.$ = micro-microwatt.
 ν = specific reluctance.
 ξ = field strength.
 π = 3.1416.
 ϕ = phase angle; power factor; flux (magnetic lines of force).
 $\omega = 2\pi f$; ohms.
 Ω = ohms (standard); megohms.
 $\propto$ = is proportional to; varies as.
 $\sim$ = cycle.
 ∞ = infinity.
 φ = angle.
 $| |$ = r.m.s. magnitude ($|E|, |Z|$).
 $\therefore$ = therefore.
 Δ = (delta) change, variation.
 $\neq$ = is not equal to.
 $\pm$ = plus or minus.

GREEK ALPHABET

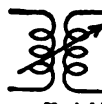
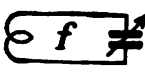
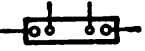
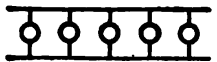
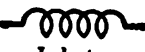
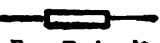
Letters		Names	Letters		Names	Letters		Names
A	α	Alpha	I	ι	Iota	P	ρ	Rho
B	β	Beta	K	κ	Kappa	Σ	σ, ς	Sigma
Γ	γ	Gamma	Λ	λ	Lambda	T	τ	Tau
Δ	δ	Delta	M	μ	Mu	Υ	ν	Upsilon
E	ϵ	Epsilon	N	ν	Nu	Φ	φ or ϕ	Phi
Z	ζ	Zeta	Ξ	ξ	Xi	X	χ	Chi
H	η	Eta	O	$\omicron$	Omicron	Ψ	ψ	Psi
Θ	θ	Theta	Π	π	Pi	Ω	ω	Omega

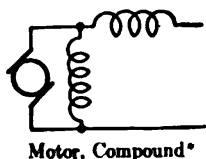
COMMON PREFIXES

Abbrevi- ation	Prefix	Numerical equivalent		Base and exponent	Charac- teristic of logarithms
meg. k.	mega	1,000,000		10^6	6. —
	kilo	1,000		10^3	3. —
		Fraction	Decimal		
deci.	deci	1/10	0.1	10^{-1}	— 1. —
c.	centi	1/100	0.01	10^{-2}	— 2. —
m.	milli	1/1000	0.001	10^{-3}	— 3. —
μ	micro	1/1,000,000	0.000001	10^{-6}	— 6. —
$\mu\mu$ (mm.)	micromicro	1/1,000,000,000,000	0.000000000001	10^{-12}	— 12. —

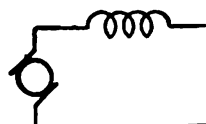
RADIO SYMBOLS

Most of the symbols appearing on this and the following page are standardized and reproduced by courtesy of the Institute of Radio Engineers. Those symbols marked with an asterisk (*) are not standardized by the I.R.E. but are adopted from electrical- and radio-engineering practice.

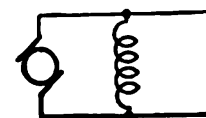
		
Ammeter	Transformer, Air Core	Alternator, Two Phase*
		
Antenna	Transformer, Variable Coupling	Alternator, Three phase*
		
Arc	Crystal Detector	D.-C. Motor or Generator*
		
Battery (positive electrode, long line)	Frequency Meter (wavemeter)*	Ammeter Shunt*
		
Busser*	Galvanometer	Circuit Breaker*
		
Loop Antenna	Ground	Lamp Bank*
		
Fixed Condenser	Inductor	Fuse, Link Type*
		
Fixed, Shielded Condenser	Inductor, Iron Core	Fuse, Enclosed*
		
Variable Condenser	Inductor, Variable	Fuses, Plug*
		
(a) Variable Condenser (moving plate indicated)	Inductor, Adjustable (by steps)	Counterpoise
		
(b) Variable, Shielded Condenser	Alternator, Single Phase*	Voltmeter



Motor, Compound*



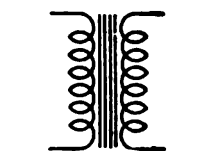
Motor, Series*



Motor, Shunt*



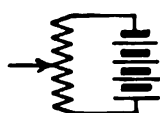
Switch Knife (SPST)*



Transformer, Iron Core



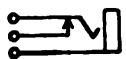
Variometer*



Potentiometer*



Wattmeter*



Jack



Key



Lightning Arrester*



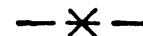
Resistor



Resistor, Variable



Resistor, Adjustable (by steps)



Spark Gap, Rotary Synchronous



Spark Gap, Quenched



Spark Gap, Plain



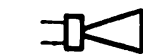
Spark Gap, Rotary Non-synchronous*



Piezo-electric Plate (crystal)



Telephone Receivers



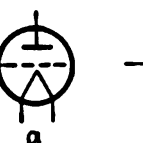
Loud Speaker



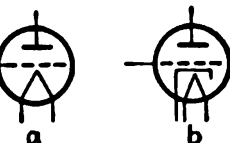
Microphone (telephone transmitter)



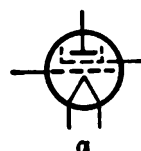
Thermoclement



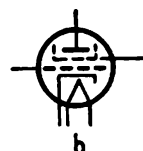
(a) Triode (with directly heated cathode)



(b) Triode (with indirectly heated cathode)



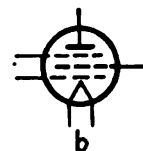
(a) Screen-grid Tube (with directly heated cathode)



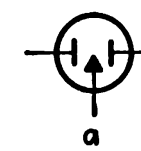
(b) Screen-grid Tube (with indirectly heated cathode)



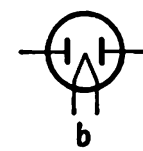
(a) Tetrode (with directly heated cathode)



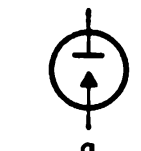
(b) Pentode (with directly heated cathode)



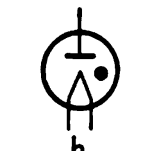
(a) Rectifier Tube, Full Wave (with cold cathode)



(b) Rectifier Tube, Full Wave (with directly heated cathode)



(a) Rectifier Tube, Half Wave (with cold cathode)



(b) Rectifier Tube, Half Wave (Diode) (with directly heated cathode—dot indicates gas tube)



Phototube



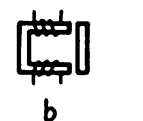
Wires, Joined



Wires, Crossed, Not Joined



(a) Closed core transformer*



(b) Closed Core Transformer with Adjustable Leakage Gap*

PRACTICAL RADIO COMMUNICATION

CHAPTER 1

DIRECT-CURRENT ELECTRICITY AND MAGNETISM

The *precise* nature of electricity is as undefined today as it was when electrical effects were first noticed centuries ago. Its manifestations, however, are now quite well understood, and from these, modern science has been able to construct a theory of electricity which satisfactorily explains most electrical actions.

It is upon this theory of electricity, known as the *electron theory*, that the art of radio is based. It is consistent, therefore, that a study of radio communication should begin with an exposition of the fundamental concepts of electricity as outlined in this chapter.

I. ELEMENTARY ELECTRICITY

1.1. Electric Charges and Forces.—It has been found that when certain bodies are subjected to friction they possess a property of attraction or repulsion, depending upon the character of the materials used. This property has been defined as electricity or electrical energy, and is generally referred to as electrical charges showing differences in behavior. This is to say that, if one body acts in a definite manner, it is said to be positively electrified; and, if it acts in an opposite manner, it is said to be negatively electrified. It is merely an arbitrary expression of behavior to state that a body is positively or negatively electrified, charged, or excited. If a body does not react at all, it is said to be neutral, that is, the positive and negative charges are equal and therefore neutralize one another.

If a piece of sealing wax is rubbed with fur, it is found that it acquires abnormal powers to attract other lighter bodies. This force of attraction is actually large enough to attract small bits of paper or deflect a suspended pith ball against the force of gravity.

If a pith ball is suspended from a silk thread, as illustrated in Fig. 1-1(a), and touched with a charged ebonite rod, the ball will acquire a negative charge. This is due to the ball receiving some negative particles of electricity from the rod, which consequently leaves it in an excessively

negative state. The ebonite rod will then repel the ball. If a charged glass rod is touched to another pith ball, some negative particles will pass from the ball to the glass, leaving the ball positively charged. The two pith balls thus oppositely charged and placed in the vicinity of one another will attract each other. Hence the law: *Like charges repel and unlike charges attract one another.*

Figure 1-1(a) may be used to show the phenomena of electrical forces existing between bodies and will serve as an illustration of a testing instrument for detecting small positive or negative forces. By applying negative particles to the suspended pith ball as previously stated, the instrument may be used as an effective electroscope to detect the presence and kind of charge in other bodies.

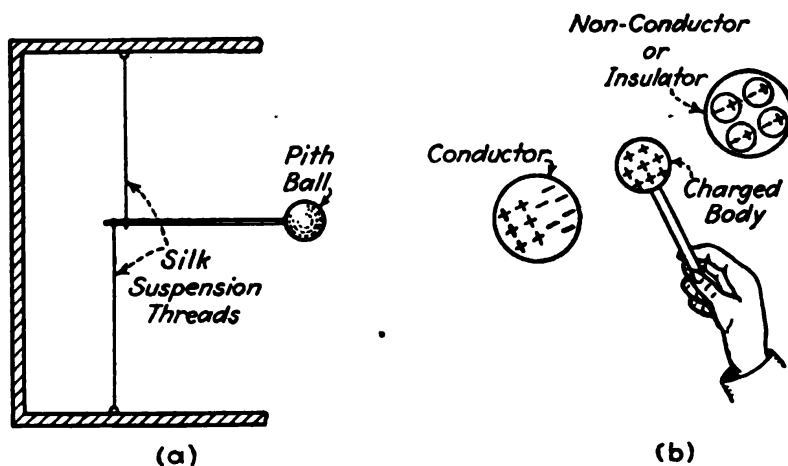


FIG. 1-1.—Phenomena of electrical forces between two bodies.

Any two dissimilar materials brought in contact become more or less charged with equal amounts of opposite kinds of electricity.

Uncharged or neutral bodies are believed to be composed of equal amounts of positive and negative particles of electricity. Thus, if a charged body is placed near it, the interior positive and negative particles of electricity are displaced in the manner illustrated in Fig. 1-1(b). It will be noted that the external charge attracts the unlike charge in the neutral material, and repels the like charge. If the material is a conductor, the negative charges are shifted to one end of the sphere and the positive charges to the opposite end. This is probably due to the fact that many of the negative particles move about freely in conductors, while in insulating materials or poor conductors the negative charges are bound, and are therefore not free to move about. In good insulating materials, there are assumed to be few or no free charges, and yet attraction with charged bodies may result owing to the formation of the charge into small doublets. An approaching charge will attract these doublets as illustrated in Fig. 1-1(b).

It is this production of a state of strain between bodies that is called *electric or static lines of force*. The presence of these lines is fairly conclusive proof that all matter is a fundamental manifestation of electricity.

Matter in the general sense may be defined as anything that has weight, such as solids, gases, and liquids. Matter is believed to be composed of molecules which in turn are made up of one or more of the 92 known chemical elements. These elements of which the molecule is composed are known as *atoms*.

1.2. Protons and Electrons.—Matter, therefore, may be imagined as being made up, in the last analysis, of small individual bodies called *atoms*, which in turn are made up of small quantities of positive and negative charges called *protons* and *electrons*, respectively. The physical dimensions of these minute particles are now definitely known, particularly under conditions of rest. The proton has been calculated to have a mass 1.66×10^{-24} gram when at rest, and the electron to have a mass of 8.99×10^{-28} gram when at rest. These particles have a definite amount of charge about them which is called the *electrostatic field*. This field is a stationary one and is measured in units called *electrostatic units* or more recently *statcoulombs*. The statcoulomb, therefore, is an expression of the number of units of electricity or electric lines of force present when a body is at rest. The proton and electron both possess an indivisible charge about them of 4.77×10^{-10} electrostatic lines or statcoulombs.

From these dimensions it is quite apparent that the mass of an electron is an insignificant part of the total mass which is almost entirely the proton. This condition has now been definitely proved by the hydrogen atom, which incidentally is the smallest of all the atoms, and which contains one proton and one electron. In other words, the mass of a proton is substantially equal to the mass of the hydrogen atom which is calculated to weigh 1,840 times as much as an electron.

An atom is therefore a sort of solar system with a sun and planets and empty regions. These empty regions are of vastly greater dimensions than the imaginary sun and planets, so much so that in reality the greater part of a molecule, and in turn all matter, is unoccupied, although it may seem to us to be solid, gaseous, or liquid. In this imaginary solar system which makes up the atom we might conceive of the planets as the electrons and the sun as nuclear protons. It thus seems logical and according to scientific research findings that the weight of a body is dependent upon its atomic structure, and, in turn, that the activity in or outside of the atom is dependent upon the number of electrons around the nucleus.

When an atom has many electrons, it seems that they are arranged in successive orbits around the nucleus and revolve around it in either ellipses or circles. It is now definitely known that the chemical and electrical properties of the atom depend almost entirely upon the outer ring of electrons. Copper and silver, for example, are classified as good conductors of electricity, probably due to the fact that the orbital arrangements of the electrons in these materials are such that the electrons in the outer orbit are more free to roam about than the outer orbital electrons of other materials. The electrons located in the inner structure of the atom are called *nuclear* electrons, and those in the orbits are called *orbital* electrons.

Figure 1-2 illustrates the arrangement of protons and electrons in a helium atom, showing both the nuclear and orbital electrons. It is now believed that nuclear electrons occur only as parts of a newly discovered entity called the *neutron*, the combination being located between the protons as compensating forces, since the repellent tendency of the four protons would otherwise cause them to fly apart.

Thus in all atoms, beginning with the hydrogen atom, which has one proton and one electron, up to the uranium atom, which has 92 protons and 92 electrons, the electrons are arranged in various orbits, and each element manifests certain chemical and electrical phenomena dependent

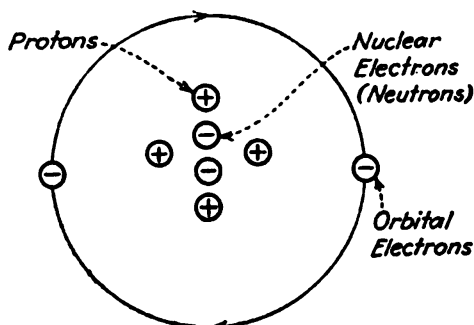


FIG. 1-2.—Arrangement of protons and electrons in a helium atom.

almost entirely upon the orbital motion of electrons, particularly in the outer ring.

It is now definitely known that in certain materials electrons are constantly changing from one orbit or orbital position to another. Under these conditions the material is constantly radiating energy into space which gradually causes its disintegration. This process takes place in

those elements containing between 83 and 92 electrons in their atomic structure such as bismuth and uranium, respectively. Those elements of lower atomic numbers do not disintegrate by radiation unless they are subjected to a considerable rise in temperature under which condition disintegration takes place.

Although physicists have also found other small entities to be included within the structure of the atom, the reader need not feel that a knowledge of their behavior is essential for an understanding of the flow of electrical current as treated in this text. In view of the frequent reference to these units in scientific literature, however, a brief summary of their characteristics will be given here.

The outstanding addition as a new particle of matter is the *positive electron*, which has been christened the *positron*. The existence of this particle was discovered by Dr. Carl D. Anderson in 1932. It is believed to consist of positively charged particles or corpuscles or rays. Its mass is equal to that of the electron but is of opposite polarity. Its charge, therefore, is like that of the proton although the latter has been computed to be approximately 1,840 times more massive.

The positron, according to Dirac,¹ is born of radiation and possesses an extremely short life since it is immediately absorbed by surrounding matter and dies only to give birth to new radiation. The precise manner of its annihilation and rebirth has been deduced from the fact that when it strikes a free electron both particles are annihilated and give rise to what are known as *photons* or *gamma rays* which travel in opposite directions with a total energy of a million *electron volts*.

It must not be believed, however, that the positron is a preexisting particle of matter in an atom such as the proton, neutron, and electron; it is rather a particle entirely born of radiation.

¹ Cambridge, England. He shared in the 1933 Nobel physics prize.

1.3. Potential.—The term *potential* is commonly used to express the level of any point in space. In an electric field, for example, the potential of a point has the same meaning as has potential energy to a point in the gravitational field of the earth. That is, the potential of any point above the surface of the earth (ground) may be defined as the amount of energy that is required to raise a unit mass of matter from the earth to that point. More energy or work is required to raise it to a greater height from the earth, and therefore the potential energy required is said to be greater. When a mass is raised to a point at the limit of the gravitational field of the earth or, in other words, to an infinite distance, then its potential with relation to the earth is at its maximum.

It is generally regarded that the outermost boundary of an electric field has an absolute zero potential and that, therefore, this *absolute potential* of any point in a field may be defined as the quantity of work required to bring unit mass, if the field is gravitational, from infinity to that point. Similarly the *absolute electrical potential of a point is defined as the work necessary to bring a unit-positive charge from an infinite distance to the point*. If the field is due to a positive or negative charge, the potential of any point in the field is either positive or negative, since work must be performed by an external force, and by a resisting field. Therefore, the potential energy of the unit positive or negative charge will be increased when it is moved closer to the charge which is repelling it.

In an electrical circuit we say that a current flows when an electrical potential difference exists between the two ends of the circuit. Hence, if two oppositely charged bodies are connected by a conductor, a current will flow from the negative to the positive point or from the point of low potential to the point of high potential. For example, if the + and the - charges of Fig. 1-3 are connected by a conducting wire, the electrons will pass from the negatively charged body to the positively charged body, and in doing so will carry one end of the lines of force with them, finally shortening the lines until they disappear. Hence the strain between the bodies is said to be relieved and the potential difference drops to zero.

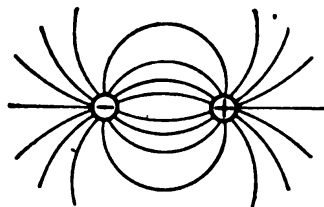


FIG. 1-3.—Electric field between two oppositely charged bodies.

The potential difference (*PD*) between any two points may be defined as the amount of work required to move a unit-positive charge from one point to another.

From this it may readily be seen that whenever work is being done by moving charges in an electric field a difference of potential must exist between the two charged bodies. In other words, differences in potential must exist wherever there is an electric field, and an electric field must exist whenever there are differences of potential.

If it is desired to find the electrical potential at a point near a charged body we may do so by the following reasoning.

In Fig. 1-4 the point *A* is a charged unit with a certain number of statcoulombs which will be called *Q* units of electricity. To obtain the difference of potential, *PD*, between the point *p*₁ at a certain distance *d*₁ from the charged body *A*, and the point *p*₂ at a distance *d*₂ from the charged body *A*, the strength of the electric field at the point *p*₁ may be

obtained by taking the ratio of the electric units to the distance squared, or $\phi_1 = Q/d_1^2$; similarly, at the point p_2 , by the ratio $\phi_2 = Q/d_2^2$. Now, since the potential difference is the work required to move unit-positive charge from p_2 to p_1 , that is, over distance d_3 , and if the strength of the field is equally distributed between p_2 and p_1 , the amount of work done

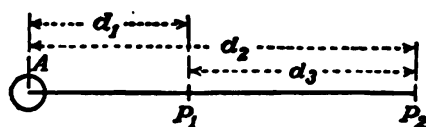


FIG. 1-4.—Illustrating the difference of potential between a charged body A and various points P at various distances d .

is found by multiplying the strength of the field by the distance d_3 . However, since this force or strength of the field varies inversely as the square of the distance from A , the average force can be obtained only by taking the geometric average of the two forces p_1 and p_2 , thus,

$\sqrt{\frac{Q}{d_1 \times d_2}}$. The work or the potential difference may then be obtained by taking the product of the average strength of the field times the distance. Hence,

$$PD = \frac{Q}{d_1 \times d_2} \times (d_2 - d_1) = Q \left(\frac{1}{d_1} - \frac{1}{d_2} \right) \quad (1)$$

If it is required to obtain the absolute potential E_1 of the point p_1 , the point p_2 must be moved to an infinite distance from A . Hence, the potential difference E_1 at the point p_1 will be equal to the ratio of the statcoulombs to the distance d_1 , or Q/d_1 . From this it may readily be seen that the potential due to a charged point varies directly as the charge and inversely as the distance from the charge. A generalization may now be stated as *Coulomb's law*, as follows. *Force is inversely proportional to the square of the distance between electrically charged particles.*

1.4. Free Electrons in Solid Conductors.—In order to understand electric phenomena, as associated with the flow of current in a circuit, some idea as to the atomic structure in this relationship must be understood.

Various phenomena point to the existence of roving electrons in a solid conductor called *free* or *conduction electrons*. It is believed that these electrons are constantly moving from atom to atom in a conductor with a movement which resembles an elliptical motion. That is to say, some electrons leave their respective atoms and move toward other atoms inside the conductor without being forced to do so by the application of an exterior electrical pressure.

These electrons apparently do not travel from end to end in a conductor, as they do in an electrical circuit when some external potential is applied. They probably move from atom to atom and, like little planets, swing around their nuclei.

Thus we must imagine them to have left their orbits in the atoms of the solid and to be moving about in the solid in a sort of haphazard

way. Consequently the atoms that have lost an electron are positively charged but, even though they are in motion because of material temperature, are not free to move about the solid. This is due to the effect of molecular forces in the vicinity of these atoms which hold them in their definite positions. It is apparent here that the free electrons moving about may again recombine with atoms, but in the same material their number per cubic centimeter is assumed to be almost universally constant; that is, when one electron recombines, another electron becomes free. At temperatures above $450^{\circ}\text{C}.$, these free electrons actually force themselves through the surface of the metal and radiate energy into space. At normal metal temperatures the free electrons that take part in the transfer of electricity are sometimes called *conduction electrons*.

1.5. Electric Current.—The modern conception of an electric-current flow in a conductor, as accepted by physicists, is based upon the theory of conduction electrons; in other words, that an electric current may be defined as a progressively moving electron, or electrons. This may give the impression that an electric current is actually flowing in a wire having both ends open, since free or conduction electrons are actually in motion. That is true, but, since the electrons do not actually flow from one end of the wire to the other end unless they are forced to do so by the application of some external potential, they are not considered “flowing” from the electric-current point of view. However, as soon as the two ends of a conductor are connected to a battery or generator this movement of electrons begins and continues around the entire circuit in a definite direction, depending upon the polarity of the battery or generator, as long as the difference of potential is applied.

Motional Velocity of Electrons.—When a potential is applied to two ends of a wire conductor to form an electric circuit, the electrons move around the entire circuit from the negative terminals of the battery or generator to the positive terminals. This is contrary to the earlier belief that a current always flows from the positive terminal through the conducting medium to the negative terminal. This latter conception is still maintained in many textbooks only to conform to the conventional standard of direction.

When it is said that a current is flowing from the positive to the negative terminals of a battery or generator this merely expresses the *conventional* flow of an electric current. But it is, nevertheless, true that electrons are moving in the opposite direction, that is, from the negative terminal of the potential supply through the metallic conductor toward the positive terminal. Hence, the current flow in a metallic conductor must always be looked on as an electron drift toward the positive terminal from the negative terminal of the battery or generator.

It is important to note that the electrons do not move at a high rate of speed through the metallic conductor when the potential is applied.

That is to say, the progressive motion of the electrons in a metallic conductor is very slow. The electrical impulse or signal set up by the electron movement, however, is very fast and attains the velocity of an electric wave through the conductor or surrounding medium. This is analogous to a heavy freight train which when starting moves as a whole very slowly, but on which the pulling force or energy is transferred very quickly with a jerk from the engine to the last car.

The slowness of the actual electron movement is due to the fact that the free electrons are constantly colliding with the atoms in the metal, consequently retarding their progressive motion. On the other hand, it must not be thought that the actual velocity of the electrons is low. If it were not for the constant collisions with the atoms of copper in the wire, the electrons would actually reach velocities many millions of times as great as their normal drift. However, since the copper atom or molecule is many thousand times as great as that of the electron, the numerous collisions prevent a rapid progressive motion. The electrons, therefore, bound and rebound at tremendous velocities in the copper wire, always moving toward the positive electrode; thus producing an electron drift through the entire conductor.

It can readily be seen that the electron would acquire tremendous velocities if it did not collide with the relatively larger masses of atoms or molecules in the wire. Proof of this tremendous accelerating action is seen in hot metals. The heating of a body tremendously increases the atomic and molecular agitation, and the electrons may be accelerated to such a high degree that they are actually forced out through the surface of the metal. Under these conditions electrons are known to have reached tremendous velocities in the order of thousands of miles per second.

Summarizing, it is believed that the existence of free electrons in the conductors is the real reason for the manifestation of an electric-current flow in an electric circuit when a pressure is applied. It is therefore also to be assumed that any material or body which is so atomically constructed as to be devoid of or deficient in free electrons is a poor conductor. This seems to indicate that materials classified as insulators are apparently lacking in free-electron movement within their atomic and molecular structure, and that conductors offer resistance to current flow in inverse proportion to the number of free electrons present in their molecular structures.

The reader must bear in mind that the only true flow of current in solid conductors is the electron drift through the circuit from the point of negative potential to the point of positive potential, the potential in electric circuits being provided by batteries or generators.

In gases or liquids the current flow is in both directions. This action will be described in detail later.

1.6. Electromotive Force.—In order to maintain a steady flow of current in an electric circuit, there must be a constant pressure and a suitable path through which the current may flow. The pressure in electrical circuits is called the *electromotive force*, or e.m.f. In hydraulic systems the pressure is referred to as a certain number of units or pounds

per square inch. Electrically this pressure is expressed in units called *volts*, which are the units used to denote the difference of potential or electromotive force. Hence, when the e.m.f. of a battery or generator is mentioned, the reference is to its pressure as being a certain number of volts.

The electron viewpoint on the theory of potential difference is of far greater importance than the more generally accepted hydraulic analogy, because it expresses more definitely the actual conditions which take place in an electric circuit. For example, let us refer to Fig. 1-5 which represents a simple electric circuit of copper wire connected to the terminals of a battery or generator E .

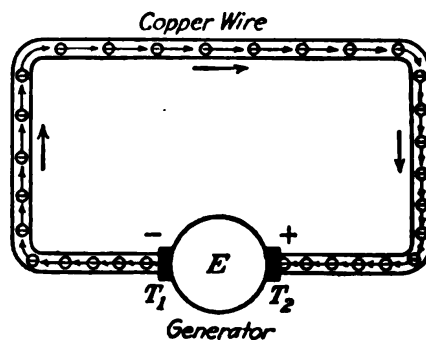


FIG. 1-5.—A simple electrical circuit showing current flow.

The circuit must be visualized as a continuous conductor completed through the medium of the generator winding between the terminals T_1 and T_2 . When the generator is set in motion, a generation of e.m.f. takes place (to be explained in Chap. 17), and an e.m.f. is exerted between the terminals T_1 and T_2 . This establishes a difference of potential which will make one terminal of the generator positive (+) and the opposite terminal negative (-). Now, since the entire circuit forms a continuous path through the conductor and the generator winding, the force exerted by the generator in motion causes the free electrons in the copper-wire conductor to be moved in the direction of the arrows, as indicated in the diagram. The electrons progressing around the conductor in the direction of the positive terminal are said to be moving from a point of low potential to one of a higher potential. The reason for this progressive motion is probably due to the fact that electrons in the generator winding have been displaced during the time in which the generator is in motion. This condition may be hypothesized by the illustration in Fig. 1-5, where E again represents the terminals of the generator.

When the generator is put in motion, a displacement of electrons in the generator winding will force a number of free electrons into the conducting wire at the negative terminal T_1 . The displaced electrons now moving in the direction of the arrow into the conductor will repel other free electrons in the wire beyond them. Hence there will be a succession of forces transmitted through the entire wire by virtue of these displaced electrons. Thus the continuous displacement of electrons in the generator armature during its motion causes all the free electrons in the conductor to move around the circuit from T_1 to T_2 producing what is generally known as an *electric current*.

It is important to note that the same number of electrons must pass any given point in the conductor in a given time so long as the current remains constant. This can be readily visualized if one imagines a long pipe filled with billiard balls which are receiving a steady series of pushes at one end causing the balls in the entire pipe circuit to move. Hence, the movement of the balls will be the same at every section of the circular tunnel (pipe) regardless of the section at which the pushes are

produced. Electrically this means that a current flow is the same at any portion of a simple circuit.

1.7. Current Strength and Quantity.—The rate of flow of water through a pipe is measured as so many gallons a second, which expression includes a definite quantity of water and a unit of time. The distinction between the terms *rate of flow* (strength) and quantity must be carefully understood in order to comprehend the practical application of these terms to electric circuits. For example, at the rate of 1 gal. of water per second, there might be 3,600 gal. of water delivered to a tank in 1 hr., thus distinguishing the rate of flow from the quantity, and naming it. Electrical quantity is measured in *coulombs*. In referring to the relation between quantity and rate of flow in an electric circuit, the electrical term for rate of flow or strength must be used. This unit is called the *ampere*. When one practical unit of quantity of electricity (coulomb) flows continuously every second, the rate of flow, or the strength, is said to be 1 amp., or, if 2 coulombs flow continuously every second, the strength of the current would be 2 amp., and so on. Hence, it can be readily seen that the current in amperes is independent of the length of time the current flows in a given circuit, regardless of whether it flows for a fraction of a second or for hours.

To find the total quantity of current flowing through a circuit in a given time, multiply the amperes by the time (in seconds),

$$Q = I \times t \quad (2)$$

Example: If an incandescent lamp requires a current of $\frac{1}{4}$ amp. to maintain a steady brilliancy, what quantity of electricity would be consumed if the lamp is lighted 2 hr.?

$$2 \text{ hr.} = 60 \times 60 \times 2 = 7,200 \text{ sec.}$$

Formula and Computation:

$$\begin{aligned} Q &= I \times t = \frac{1}{4} \times 7,200 \\ Q &= 1,800 \text{ coulombs} \end{aligned}$$

To find the average current strength (in amperes) when the quantity and the time are known:

$$I = \frac{Q}{t} \quad (3)$$

Proof:

$$\begin{aligned} Q &= 1,800 \text{ coulombs} \\ t &= 7,200 \text{ sec.} \\ I &= \frac{1,800}{7,200} \\ &= 0.25 \text{ or } \frac{1}{4} \text{ amp.} \end{aligned}$$

To find the time (in seconds) required for a given quantity of electricity (in coulombs) to pass a certain point of a circuit:

$$t = \frac{Q}{I} \quad (4)$$

Proof:

$$Q = 1,800 \text{ coulombs}$$

$$I = \frac{1}{4} \text{ amp.}$$

$$= \frac{1,800}{\frac{1}{4}}$$

$$= 7,200 \text{ sec.}$$

1.8. Electrical Resistance and Conductivity of Materials.—When water flows through a pipe, the resistance it meets depends directly on the length of the pipe, its diameter, and general conditions, such as bends and roughness. Similarly, when a difference of potential is applied to an electric circuit, a current flows through the circuit, and the amount of opposition (resistance) offered to the flow is proportional to the resistivity of the wire, which in turn depends upon the character of the material through which the current flows, its length, diameter, and temperature.

It will be remembered that the materials having less free or conduction electrons in them are classified as poor conductors or resistances. Hence alloys which have less free electrons in them than copper or silver are higher resistance materials, and the progressive flow of electrons will be relatively less; consequently we say that the current through any such material will be reduced. All metals, therefore, have a certain amount of resistance or conductivity which depends upon their atomic structure.

When pure metals are heated, through excessive current flow or otherwise, some of the electron acceleration in the material may be greatly increased. This may result in a greater number of electron impacts with the atoms, consequently reducing the progressive motion of electrons in the conductor. It is true, whatever the cause, that heated metal wires have greater resistance than cool wires, depending upon the amount of heat and the character of the metal.

It has been found that the electron flow in certain alloys when placed in an atmosphere approaching *absolute* zero temperature is practically unimpeded. That is to say, owing to the fact that all molecular motion in heatless bodies is reduced to zero, practically *no resistance* is offered to the progressively moving electrons when an electromotive force is applied. The *absolute* zero temperature, commonly known as the Kelvin temperature, abbreviated K., is 460 degrees below zero on the Fahrenheit scale or 273 degrees below zero on the centigrade scale. Hence it may readily be seen that at ordinary temperatures there is an ever present molecular agitation which consequently introduces an opposition or resistance to the flow of free electrons.

The resistance of carbon varies inversely with temperature. In other words, the resistance of carbon decreases as the carbon gets hot. Therefore, the *hot* resistance of a carbon lamp is less than its *cold* resistance. On the other hand, the resistance of a tungsten or other metallic-filament lamp, including metallized carbon, increases with increased temperature. The hot resistance of a tungsten filament is about twelve times its cold resistance.

The resistance of certain (most) alloys, such as German silver, does not vary appreciably with temperature.

The resistance of electrolytes decreases as the temperature rises.

The following table illustrates the relative resistance and conductance values of different pure metals and alloys when operating under the temperatures indicated.

TABLE IA¹.—RELATIVE CONDUCTANCES AND RESISTANCES OF CONDUCTORS

Material	Resistance of a 1 cir.-mil.-ft. (ohms)		Relative conductivity (as compared with copper)	Relative resistance (as compared with copper)
	30°F.	75°F.		
Silver, pure annealed.....	8.83	9.67	108.6	0.925
Copper, annealed.....	9.59	10.5	100.0	1.00
Copper, hard drawn.....	9.8	10.75	97.8	1.02
Aluminum, 95 per cent pure	16.03	17.7	59.8	1.67
Zinc, pure.....	34.6	37.9	27.7	3.60
Iron wire.....	58.7	65.1	16.2	6.17
Nickel.....	74.1	85.13	12.95	7.72
Steel wire.....	81.16	90.15	11.6	8.62
Brass.....	43.31	45.4	22.15	4.51
Phosphor-bronze.....	51.0	51.8	18.8	5.31
German silver.....	127.0	128.7	7.5	17.32

An examination of the above table shows that the resistance of alloys is very much greater than that of the pure metals. This is a characteristic property of alloys, which is taken advantage of in the preparation of wires of high specific resistance. Even a slight trace of another metal, which by itself may be a good conductor, has an enormous effect on the resistance; hence, copper used for electrical purposes has to be exceptionally pure.

The resistance of any material is expressed in *ohms*. (The electrical sign for the ohm is usually shown thus ω .) This is the term used to express the resistance of an electrical circuit in ohms per unit length. For example, the resistance of 1,000 ft. of copper wire which has a diameter of $\frac{1}{10}$ in. (No. 10 B. and S. gage) is about 1 ohm, although a piece of iron wire of the same length and cross section has a resistance of about 6 ohms, and a similar piece of German silver wire has a resistance of 17 ohms.

1.9. Ohm's Law.—In any circuit through which there is a flow of current we must obviously have all of the three following factors present: (1) the *pressure* or *potential difference* (volts) which causes the current to flow; (2) the opposition or *resistance* (ohms) which must be overcome to produce a current flow; (3) the *current strength* (amperes) which can be maintained in a circuit as a result of the pressure overcoming the resistance and thus causing a flow. In any circuit there is always a definite relation between these three units; and, therefore, the value of any one unknown factor may be calculated when the values of the other two are known. The law governing these calculations is known as Ohm's law.

¹ Tables are designated by both number and letter. The number indicates the chapter in which the table is located, the letter gives the table sequence.

RULE 1: *The current strength in any circuit is equal to the e.m.f. applied to the circuit, divided by the resistance of the circuit.*

$$\text{Current} = \frac{\text{pressure}}{\text{resistance}}$$

or

$$I = \frac{E}{R} \quad (5)$$

Example 1: If an electric lamp having a resistance of 55 ohms is connected across a potential of 110 volts, what current will flow through the lamp?

$$I = \frac{E}{R} = \frac{110}{55}$$

$$I = 2 \text{ amp.}$$

The current strength in any circuit increases or decreases directly with the increase or decrease in the potential, when the resistance in the circuit is assumed to be constant. If the pressure is constant, the current will increase as the resistance is decreased, and decrease as the resistance is increased.

In other words, the current might be said to vary directly with the e.m.f., and inversely as to the resistance.

Example 2: If in the above problem the voltage is increased to 220 volts, how many amperes will flow through the lamp?

$$I = \frac{E}{R} = \frac{220}{55}$$

$$I = 4 \text{ amp.}$$

RULE 2: *The amount of e.m.f. required to maintain a certain current strength in a circuit in which the resistance is known is equal to the product of the current strength and the resistance.*

$$\text{Pressure} = \text{current} \times \text{resistance}$$

or

$$E = I \times R \text{ (written } IR\text{)}. \quad (6)$$

Example 3: How much pressure must be applied to a circuit to cause 5 amp. to flow if the resistance is 30 ohms?

$$E = I \times R = 5 \times 30$$

$$E = 150 \text{ volts}$$

The pressure varies directly with the current and resistance values. For example, if it is desired to send a greater current through the same resistance, a greater amount of pressure must be applied to the circuit, or, if the same current is to be passed through a greater resistance, then a greater pressure must be applied.

RULE 3: *To find the value of resistance required to be inserted in any circuit, so that a given current will flow under a known pressure: the resist-*

ance is equal to the pressure to be applied, divided by the current strength to be maintained.

$$\text{Resistance} = \frac{\text{pressure}}{\text{current}}$$

or

$$R = \frac{E}{I} \quad (7)$$

Example 4: A certain resistance passes a current of 7 amp. through a circuit at a pressure of 35 volts. What is the value of the resistance?

$$R = \frac{E}{I} = \frac{35}{7}$$

$$R = 5 \text{ ohms}$$

When a constant pressure is desired, the resistance must be cut in half if the current is to be doubled, or, if there is to be a constant current maintained in which the pressure is doubled, then the resistance must also be doubled.

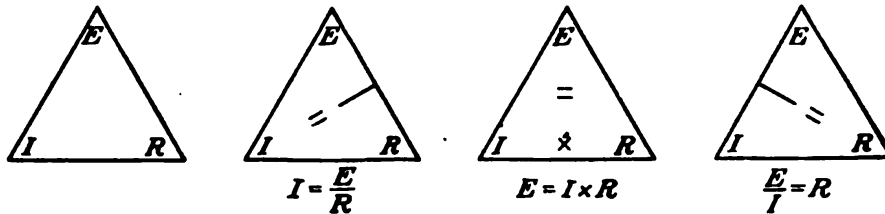


FIG. 1-6.—A simple method of remembering Ohm's law.

A simple method of remembering the Ohm's-law application to direct-current measurements is illustrated in Fig. 1-6.

For example, if the voltage and amperage in an electrical circuit are known, the pyramid diagram may be applied as follows: Place the finger over the unknown quantity, that is, the resistance R . This leaves the remaining letters E and I for the voltage and current, respectively. Thus the letter E being above the letter I simply means that the current I is divided into the voltage E to give R . If the voltage, for example, was found to have been 100 volts and the current 2 amp., then by the application of the pyramid explanation, the resistance must be 50 ohms.

Similarly, if it is desirable to find the current I if the voltage E and the resistance R are known, then, by the same application, the current can be determined by placing the finger over the unknown quantity I . For example, if the voltage E is 100 volts and the resistance R is 50 ohms, then, by application of the pyramid, it will be found that the current I will be 2 amp. Similarly, if the resistance R in an electric circuit is 50 ohms and the current I 2 amp., then, by application of the pyramid, the unknown quantity E can be determined by placing the finger over the E . Thus multiplying IR we shall find the voltage E to be 100.

1.10. Simple Electric Circuits.—Ohm's law shows that, for a given voltage, the lower the resistance the larger will be the current, and the higher the resistance the smaller the current.

Circuits are divided into three classes:

- a. Series circuits.
- b. Parallel circuits.
- c. Series-parallel circuits.

a. *Series Circuits*.—Figure 1-7 shows a simple series circuit in which may flow a steady current. This is called a series circuit because the current flows in one continuous path. Furthermore, this current is the same at any point in the circuit. An ammeter placed at any point would give the same reading. The ammeter is a device for measuring current strength in amperes.

Now, as each of these parts will have resistance, each will have what is known as an IR drop, which is always directly proportional to the resistance. Hence, each IR drop represents a certain amount of e.m.f. expenditure in each part of the circuit, and the differences of potential produced by the source must equal the total e.m.f. expended. In other words, the input must equal the output plus losses. This can be readily seen if the three parts used in all series circuits are considered.

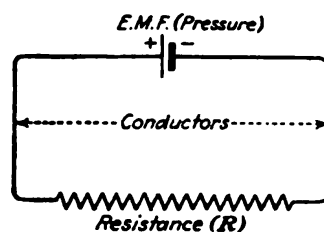


FIG. 1-7.—A simple series circuit.

1. The inside or internal part of the e.m.f. source, that is, batteries, generators, etc.

2. The leads which connect the apparatus to the source, that is, the lines.

3. The apparatus itself.

Thus, if each one of these parts has a certain amount of resistance, and the same current is flowing through them, each will have an IR drop which is proportional to its resistance. Therefore the IR drop in the source is called the *internal drop*, and that in the line is called the *line drop*. Hence, since each IR drop represents an expenditure of e.m.f., the total expenditure of e.m.f. in the circuit will be the sum of the e.m.fs. expended in each part, and, obviously, the difference of potential produced by the source must equal the total e.m.f. expended. Therefore, the supply e.m.f. must always supply a higher voltage than is required at the source terminals. The source voltage is referred to as a definite *no-load* voltage when no current is being delivered to the external circuit, and as a *load* voltage whenever current is being forced through the circuit. Obviously, there will be a certain voltage drop whenever current is drawn from a source, the amount, of course, being proportional to the resistance of the circuit.

It is seen, therefore, that any source of e.m.f. having a high internal resistance will not permit a large current to flow in the external circuit, because even a small current will cause an internal expenditure of voltage equal to the total voltage of the source and, therefore, no voltage will be available at the terminals for external use.

Figure 1-8(a) shows a series circuit with more than one resistance unit connected in series. Remembering that the same amount of current passes through every part of the circuit, the total e.m.f. will be the sum

of all the IR drops. Thus, the equivalent resistance (a resistance having a total value of the three) in a series circuit is equal to the sum of the resistances of the individual units (assuming the wires to have a negligible resistance), thus:

$$\text{Total effective resistance, } R = R_1 + R_2 + R_3, \text{ etc.} \quad (8)$$

Referring to Fig. 1-8(a), assume each resistance to have 5 ohms resistance; then what would be the effective circuit resistance?

$$R = R_1(5) + R_2(5) + R_3(5) = 15 \text{ ohms}$$

The total resistance in the circuit, therefore, would be equivalent to a circuit containing one resistance of 15 ohms, and so on. Thus, the

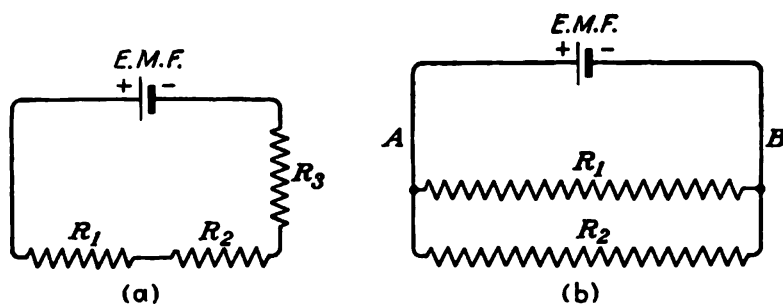


FIG. 1-8.—Series and parallel circuits.

current would be equal to the total e.m.f. divided by the total resistance, or

$$I = \frac{E}{R}$$

An important point to remember in series circuits is that, for a given voltage, the current at every point in the circuit is inversely proportional to the total resistance of the circuit.

b. Parallel Circuits.—A parallel circuit is one in which there are two or more parts connected between two points in a circuit. Figure 1-8(b) shows a simple parallel circuit consisting of two resistances R_1 and R_2 connected between two points a and b of any circuit. These resistances are assumed to have a value of 10 and 20 ohms, respectively, and to be connected across a potential of 100 volts.

How many amperes are flowing through each resistance and what is the total amperage being drawn from the supply line?

$$R_1 = 10 \text{ ohms}$$

$$R_2 = 20 \text{ ohms}$$

Then, by Ohm's law as applied to a series circuit, the current flowing through R_1 is found by dividing 100 into 10 or $I = E/R$. Thus

$$I = \frac{E}{R_1}$$

$$I = 10 \text{ amp.}$$

Then, the current flowing through R_2 will be found in a like manner to be

$$I = \frac{E}{R_2}$$

$$I = 5 \text{ amp.}$$

and so on, regardless of the number connected in parallel. The total current flowing in the exterior circuit, or in other words the combined current, is then found by adding the current flow of each part, thus

$$I = I_1 + I_2$$

or

$$I = 10 + 5 \text{ amp.}$$

$$I = 15 \text{ amp.}$$

In parallel circuits, therefore, the total current flowing through any parallel combination can always be found by applying Ohm's law to each branch and then adding the current value of each branch, as in the last example.

It can be seen, from the above statement, that the total current I is greater than can possibly be obtained through any one branch provided the impressed e.m.f. is kept constant.

From this, it is quite obvious that the joint resistance of any parallel combination is less than the resistance of any one of the branches.

For example, if three resistances of 10, 20, and 30 ohms are connected in parallel, the total effective resistance will be less than the smallest resistance. The effective resistance, therefore, can be accurately found by the formula

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \quad (9)$$

where $R_1 = 10$ ohms.

$R_2 = 20$ ohms.

$R_3 = 30$ ohms.

Hence

$$R = \frac{1}{\frac{1}{10} + \frac{1}{20} + \frac{1}{30}} = \frac{1}{\frac{6}{60} + \frac{3}{60} + \frac{2}{60}} = \frac{1}{\frac{11}{60}} = \frac{60}{11}$$

$$R = 5.45 \text{ ohms}$$

When this formula is applied to *two* resistances in parallel, it becomes

$$R_{eff} = \frac{R_1 \times R_2}{R_1 + R_2} \quad (10)$$

c. Series-parallel Circuits.—A series-parallel circuit comprises a combination of series and parallel parts. Figure 1-9 illustrates three types of series-parallel circuits. Once again Ohm's law must be applied to every part of the circuit. In analyzing more complicated circuits of this type, however, it will be necessary first to reduce each parallel combination to its equivalent series resistance and to reduce each series circuit to a single resistance before combining it with the remainder of the circuit. Then, the circuit-resistance voltage drop and current flow can be determined by Ohm's law.

For example, in circuit (a), if R_1 and $R_2 = 10$ ohms each, and $R_3 = 5$ ohms, then by reducing the parallel combination R_1 and R_2 by the parallel formula, we find the resistance to be 5 ohms. Then, by adding R_3 to the result of R_1 and R_2 , we find the total effective resistance to be 10 ohms. The same application can be made to other forms of series-parallel circuits.

The type of circuit, shown in diagram (c) of Fig. 1-9, consists of a parallel combination of series group. To solve for the total resistance,

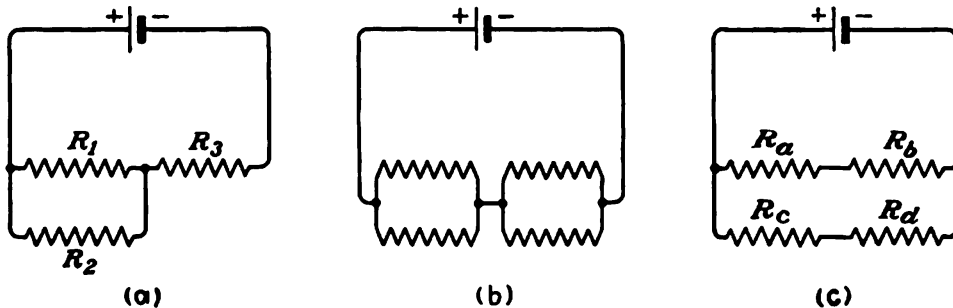


FIG. 1-9.—Series-parallel circuits.

the series of resistances in each group singly are added together and the total regarded as a single resistance. These single resistances are then regarded as being connected in parallel. For example, the total resistance of circuit (c) is computed as follows:

$$\begin{aligned} R_1 &= R_a + R_b \\ R_2 &= R_c + R_d \end{aligned}$$

The effect of R_1 and R_2 in parallel is then computed with Eq. (10) as

$$\text{Total } R = \frac{R_1 \times R_2}{R_1 + R_2}$$

If more than two series groups are involved, Eq. (9) may be used.

e. Circuit Applications.—There are, however, many variations of simple series, parallel, and series-parallel circuit problems, such as are illustrated in some of the following diagrams.

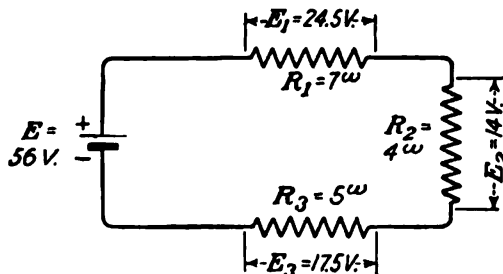


FIG. 1-10.—A simple series circuit containing three resistances in series.

Figure 1-10 is a simple series circuit containing three resistances in series. The total resistance of the entire circuit is readily determined by adding the three resistances; hence the effective resistance, $R_{eff} = R_1 + R_2 + R_3 = 16$ ohms. By the use of Ohm's law $I = E/R$, we find that the current flow in the circuit is 3.5

amp. Since the current flow in a series circuit is the same at any portion of the circuit, 3.5 amp. must flow through each resistance. Now, if it is desired to determine the voltage or potential difference across any one of the resistances, we simply apply Ohm's law, $E = IR$. Thus, if it is desired to determine the voltage across E_2 ,

multiply IR_1 , or $3.5 \times 4 = 14$ volts. It can be readily be seen that the resistances R_1 and R_2 are providing a potential drop of 24.5 and 17.5 volts, respectively. In other words, these two voltage drops deducted from 56 volts leave a balance voltage of 14 across R_3 , which proves that the sum of the voltage drops across each resistance must equal the applied e.m.f., or in this circuit 56 volts.

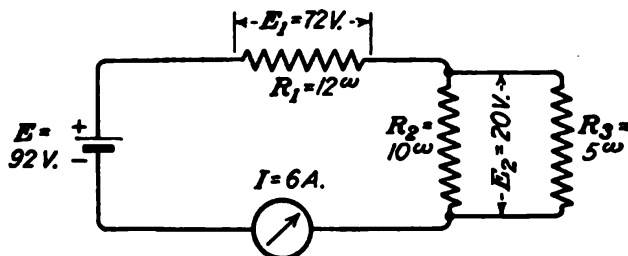


FIG. 1-11.—A series-parallel combination.

Figure 1-11 illustrates a series-parallel combination. In this type of circuit the parallel combination of 10 and 5 ohms must first be reduced to its effective resistance by the formula on parallel resistances,

$$R_{eff} = \frac{R_1 R_2}{R_1 + R_2}$$

or an effective resistance of $3\frac{1}{3}$ ohms. Since the effective resistance of R_2 and R_3 is connected in series with R_1 , the total circuit resistance may then be obtained by adding the two values $R_1 + R_{eff}$, or $3\frac{1}{3} + 12$, which is a total resistance of $15\frac{1}{3}$ ohms. The current flow in the circuit may again be obtained by Ohm's law $I = E/R = 92/15\frac{1}{3} = 6$ amp.

To prove this example we find that the voltage across $E_1 = IR_1 = 6 \times 12 = 72$ volts and $E_2 = IR_{eff} = 6 \times 3\frac{1}{3} = 20$ volts. Hence, $E_1 + E_2 = 72 + 20 = 92$ volts, which is the value of the applied e.m.f.

It will be noted that the voltage pressure across R_2 and R_3 is the same. This condition holds true in all parallel circuits since it is assumed that the connecting wires have a negligible resistance. In parallel combinations, therefore, it is a simple matter to determine the current flow through each branch by the ratio $I = E/R$.

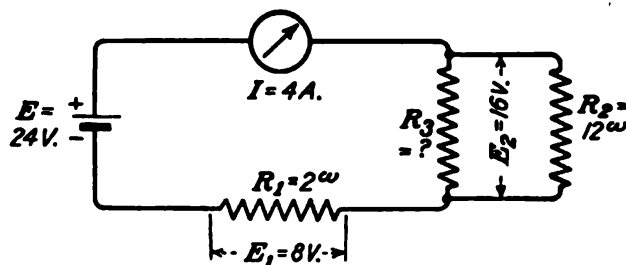


FIG. 1-12.—Another series-parallel combination.

In the preceding example we find the current flow by this ratio through R_3 is $I = E/R = 20/5 = 4$ amp.; through branch R_2 it is $I = E/R = 20/10 = 2$ amp., or a total of 6 amp. flowing out of the parallel combination.

With this form of reasoning it is possible to obtain the unknown values of any series or series-parallel combination.

For example, Fig. 1-12 illustrates a series-parallel combination in which the applied e.m.f. and total current flow are given, but one of the parallel resistances, R_3 , is unknown. To find the value of this resistance proceed as follows:

Determine the amount of current passing through R_2 , since the difference between I through R_2 and the total flow of 4 amp. must be the amount passing through the unknown resistance. When the current flow through R_2 is found, the resistance may be determined by Ohm's law $R = E/I$.

The voltage across the parallel combination E_2 must be 16 volts, since the resistance R_1 is carrying a current of 4 amp.; hence $E_1 = IR_1$, or 8 volts. Thus, if the resistance R_1 has a voltage drop across it of 8 volts, the remaining voltage across the parallel combination must be 16 volts. Hence the current flowing through R_2 is $I_2 = E_2/R_2 = 16/12 = 1\frac{1}{3}$ amp. and, since the total current flow is 4 amp., the current flow through R_2 must be $I - I_2 = 4 - 1\frac{1}{3} = 2\frac{2}{3}$ amp. Then $R_2 = E/I = 16/2\frac{2}{3} = 6$ ohms.

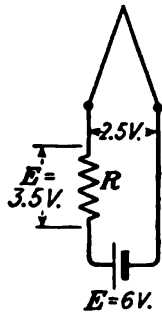


FIG. 1-13.
— Resistance
in series with
filament.

A practical application of the simple series circuit is illustrated in Fig. 1-13 in which a vacuum tube is designed for an operating e.m.f. of 2.5 volts at which voltage the tube will draw 1.75 amp. What value of resistance must be inserted to operate this tube at the required voltage if the applied e.m.f. is 6 volts?

Since the voltage across the tube terminals must be 2.5 volts, the resistance will be required to drop the voltage from 6 to 2.5 volts, a drop of 3.5 volts. Hence, if a current flow of 1.75 amp. passes through the resistance and filament, under the assumption that R is correct, we may readily determine the value of resistance to obtain the desired result by the ratio $R = E/I = 3.5/1.75 = 2$ ohms.

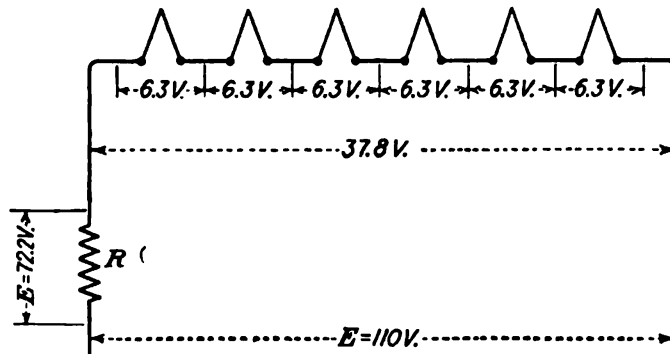


FIG. 1-14.—Filaments in series.

Similarly, if a number of low-voltage filaments are to be operated from a high-voltage supply system, the voltage must be decreased to the desired operating voltage of the tubes. For example, six tubes are to be operated from a 110-volt line and each to require a potential of 6.3 volts. At this potential each tube will draw 0.3 amp. What value of resistance must be inserted to satisfy this condition? Figure 1-14 illustrates the circuit arrangement.

If each tube requires a potential of 6.3 volts, then the effective potential of the six tubes connected in series must be 6×6.3 volts, or 37.8 volts. Hence, it will be necessary to drop the voltage from 110 to 37.8 volts, or a total drop of 72.2 volts.

The total current flow through R and all the filament resistances will be 0.3 amp. (current flow in a series circuit is the same at any portion of the circuit), if the value of R is assumed to be correct. Hence the correct value of R to effect this condition is again obtained by the ratio $R = 72.2/0.3 = 240\frac{2}{3}$ ohms.

1.11. The Shunt Law.—When an e.m.f. is applied to a network consisting of two resistances in parallel, the current divides itself between the two paths in inverse proportion to the resistance they offer to its flow. Any branch of a circuit which by-passes another branch is called a *shunt* with regard to the branch it by-passes.

Thus, in Fig. 1-15(a):

$$\frac{I_1}{I_2} = \frac{R_2}{R_1} \quad (11)$$

and, therefore,

$$I_2 = I \left(\frac{R_1}{R_1 + R_2} \right) \quad (12)$$

where I_1 and I_2 are the currents in R_1 and R_2 , respectively, and I is the

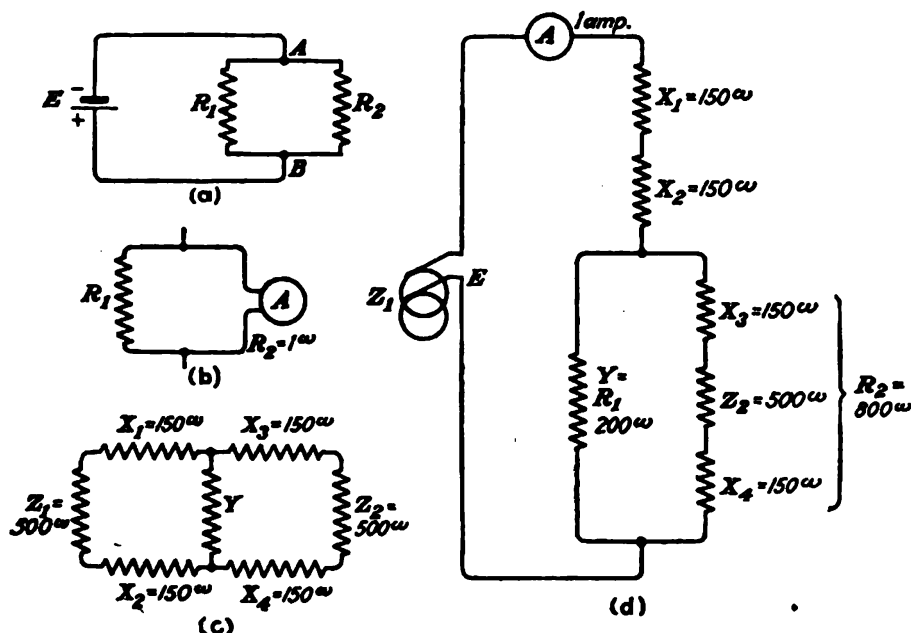


FIG. 1-15.—Circuits illustrating the shunt law.

total current flowing from A to B . The factor $(R_1 + R_2)/R_1$ is called the *multiplying factor* of the shunt.

Example 1: An ammeter A reads 0 to 5 amp. It is desired to design a shunt S to be used with the meter to cause it to read 0 to 25 amp. What should the resistance of the shunt be, if the resistance of the meter is 1 ohm? The circuit is shown in Fig. 1-15(b).

Solution:

$$\frac{R_1}{R_2} = \frac{I_2}{I_1}$$

$$\frac{I_2}{I_1} = \frac{5}{20} = \frac{R_1}{R_2} = \frac{1}{4}$$

then

$$R_1 = \frac{1}{4}R_2 = \frac{1}{4} \times 1 = \frac{1}{4} \text{ ohm}$$

The multiplying factor of the shunt R_1 is, therefore, found by the equation

$$\frac{R_1 + R_2}{R_1} = \frac{0.25 + 1}{0.25} = \frac{1.25}{0.25} = 5$$

So the shunt multiplies the current-carrying capacity of the parallel circuit R_1, R_2 by 5. Whereas the meter would register full deflection with 5 amp. flowing through the circuit without the shunt, it registers full deflection with 25 amp. when by-passed by the shunt, a multiplication of five times.

Example 2: It is desired to know what current will flow through a load resistance Z_2 of 500 ohms connected to the output of an H pad (attenuation network) as shown in Fig. 1-15(c). The equivalent of this circuit is shown as Fig. 1-15(d). The ammeter A reads 1 amp.

Solution:

$$\frac{R_1}{R_2} = \frac{I_2}{I_1} = \frac{200}{800} = \frac{I_2}{I_1}$$

Therefore

$$I_2 = I \left(\frac{R_1}{R_1 + R_2} \right) = I_2 = 1 \left(\frac{200}{1,000} \right)$$

$$= 1 \times 0.2 = 0.2 \text{ amp.}$$

If 0.2 amp. flows through R_2 , then 0.2 amp. must flow through Z_2 , as the current in all parts of a series circuit is the same.

1.12. Kirchhoff's Laws.—In the simple electric circuits explained, the equivalent resistance and the currents in the various branches are readily calculated by Ohm's law, but in cases where complex combinations involving cross connections are employed the solution cannot be derived by that law.

Equations for the solution of such problems can easily be written down by using Kirchhoff's two laws. These are not "laws" in the same sense as Ohm's law; they are merely useful rules which show how Ohm's law is to be applied.

RULE 1 (Kirchhoff's Current Law): *a. In any branching network of wires, the algebraic sum of the currents in all wires meeting at a point is zero.*

b. Kirchhoff's current law may also be expressed: The algebraic sum of the currents at any junction of conductors is always zero.

c. This current law then simply states that no electricity accumulates at any point in a circuit (under steady direct current) or that the sum of the currents toward any junction is equal to the sum of the currents away from the junction. This fact may be easily verified experimentally.

The term *algebraic sum* means that in adding up the currents at a point or junction a plus sign is to be written before each current flowing toward the junction and a minus sign is written before each current flowing away from the junction.

Figure 1-16 is a simple illustration of Kirchhoff's (first) current law, in which the sum of all the electrons moving into the junction *B* is equal to the sum of all the electrons flowing away from the junction, in other words, there is no accumulation of electrons at any point in the circuit. Hence, the algebraic sum of the currents at *B* must be zero. Therefore, applying Rule 1a or 1b, $7 + 3 + 4 - 4 - 10 = 0$, or applying Rule 1c, $7 + 3 + 4 - 4 - 10 = 0$.

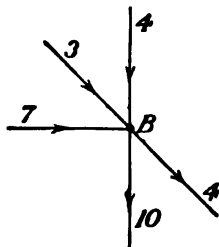


FIG. 1-16.—Illustration of Kirchhoff's first law.

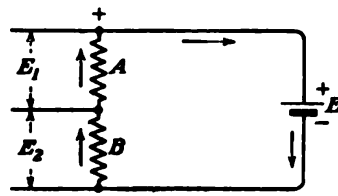


FIG. 1-17.—A circuit illustrating Kirchhoff's second law.

RULE 2 (Kirchhoff's Voltage Law): *a. In any closed path in a direct-current network, the algebraic sum of the e.m.fs. acting in that path is equal to the algebraic sum of the IR products in that path.*

b. Kirchhoff's voltage law may also be expressed: The algebraic sum of the differences of potential around any closed path in a circuit is always zero.

c. This voltage law is equivalent to a statement that the difference of potential between any two points is independent of the path traced between the two points (by an assumed positive test charge) and is equal to the algebraic sum of the differences of potential between all intermediate points. This fact may be easily verified experimentally.

A simple illustration of Kirchhoff's (second) voltage law is seen in Fig. 1-17. The law states that if the voltage E_1 is measured across the resistance *A* and the voltage E_2 is measured across *B*, the sum of these two voltages must be numerically equal to the applied voltage E , or applying Rule 2a, $E_1 + E_2 = E$; and applying Rule 2b, $E - E_1 - E_2 = 0$, or $E - IR_A - IR_B = 0$, or $E - I(R_A + R_B) = 0$. In other words, the e.m.f. E causes a difference of potential to exist across *A* and *B*, and the current in the circuit is limited (or opposed) by the sum of the two resistances. This problem reduces simply to the expression $E = I \times (R_A + R_B)$ which is equivalent to Ohm's law.

Figure 1-18 is another illustration of Kirchhoff's (second) voltage law. In this circuit, the total impressed e.m.f. acting in the circuit is $E - E_1 + E_2$, illustrating that there are two e.m.fs. supplementing each other and one opposing the two. (NOTE: The arrows beside the batteries show the direction of force on the electrons.)

Hence, since the algebraic sum of the impressed e.m.fs. is equal to the algebraic sum of the IR products in the circuit, we may write:

by Rule 2a

$$E + E_2 - E_1 = IR_1 + IR_2$$

or by Rule 2b

$$E - IR_1 - E_1 - IR_2 + E_2 = 0$$

or by Rule 2c

$$E = IR_1 + E_1 + IR_2 - E_2$$

These equations reduce simply to $(E + E_2 - E_1) = I(R_1 + R_2)$, which is again equivalent to Ohm's law.

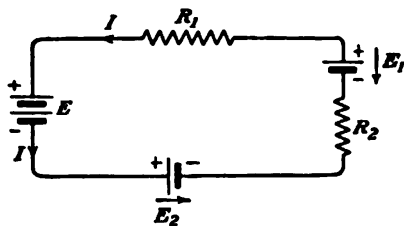


FIG. 1-18.—A circuit illustrating Kirchhoff's second law.

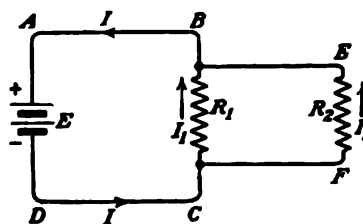


FIG. 1-19.—A circuit illustrating Kirchhoff's first and second laws.

In circuits where the direction of current is apparent, such as in Fig. 1-19, the solutions for the problem are easily obtained by Kirchhoff's first and second laws.

Applying Rule 2:

For path ABCD:

$$E = I_1 R_1 \quad \text{or} \quad E - I_1 R_1 = 0 \quad \text{or} \quad I_1 = \frac{E}{R_1}$$

For path ABEFCD:

$$E = I_2 R_2 \quad \text{or} \quad E - I_2 R_2 = 0 \quad \text{or} \quad I_2 = \frac{E}{R_2}$$

Then, applying Rule 1,

$$I - I_1 - I_2 = 0$$

or

$$I = I_1 + I_2 = \frac{E}{R_1} + \frac{E}{R_2} = \frac{E}{R}$$

It can be readily seen that circuits containing e.m.fs. acting in different directions around any path can be very easily solved if we call all the voltages which would cause the current to flow in one direction along the path *positive*, and those which would tend to cause it to flow in the opposite direction *negative*. Thus all the positive and negative e.m.fs. may be added up algebraically. Similarly, all the IR products due to current in one direction along the path are called *positive*, and those IR products due to current in the opposite direction are called *negative*.

Complex Problems.—Types of problems involving the shunt law and Kirchhoff's law are illustrated in the diagrams appearing in the remainder of this section. In Fig. 1-20 the tubes 1, 2, and 3 draw 0.3 amp. at 6.3 volts, and tube 4 draws 0.26 amp. at 2 volts. Hence, tube 4 must be shunted by a parallel resistance to prevent its filament from burning out.

The procedure toward the solution of this type of problem is exactly the same as in that for Fig. 1-14 with the exception that the shunt resistance around tube 4 must be carefully calculated. Since it must be apparent that the other tubes require 0.3 amp. and that this value flowing through tube 4 would cause it to burn out, the shunt resistance must pass the difference between the maximum value of 0.3 and 0.26, the latter value being that required for tube 4. This difference, or 0.04 amp., must mean that the correct value flowing through R_2 would then allow only 0.26 amp. to pass through the filament.

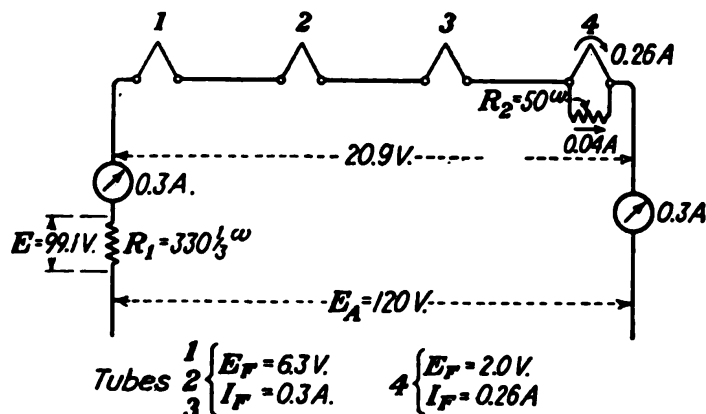


FIG. 1-20.—Another series filament circuit.

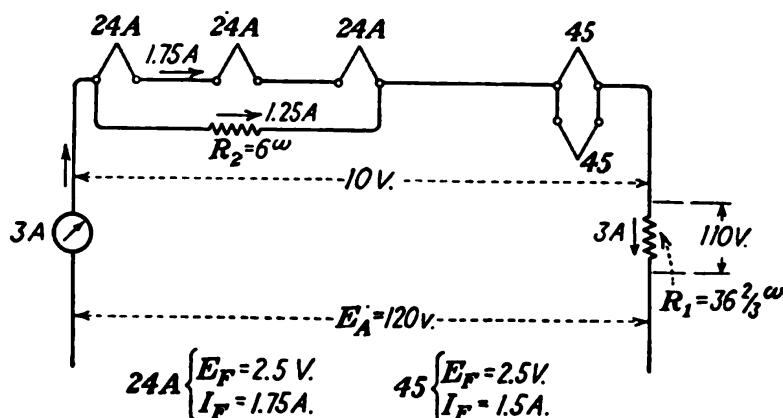


FIG. 1-21.—Series-parallel filament circuit.

Solution: The voltage drop across the series filament circuit is $(3 \times 6.3) + 2 = 20.9$ volts. Hence, the source voltage of 120 volts must be reduced by 99.1 volts.

Inasmuch as the line current is 0.3 amp., the value of the dropping resistor $= E/I = 99.1/0.3 = 330\frac{1}{3}$ ohms.

Tubes 1, 2, and 3 have a heated resistance of $6.3/0.3 = 21$ ohms each.

The filament resistance of tube 4 is calculated $R = E/I = 2/0.26 = 7.7$ ohms

Then, solving for R_2 we can apply the shunt law as follows:

$$\frac{I_1}{I_2} = \frac{R_2}{R_1} = \frac{0.26}{0.04} = \frac{R_2}{7.7}$$

Hence, $R_2 = 0.26 \times 7.7/0.04 = 50$ ohms.

Therefore, the resistance of tube 4 in parallel with R_2 is calculated

$$R_{eff} = \frac{R_4 \times R_1}{R_4 + R_1} = \frac{7.7 \times 50}{7.7 + 50} = 6\frac{2}{3} \text{ ohms.}$$

Applying Kirchhoff's second law we can prove that the IR drops around the circuit equal the applied voltage. Adding the total resistance of the circuit we obtain $330\frac{1}{3} + (3 \times 21) + 6\frac{2}{3} = 400$ ohms.

Hence, $E_A = IR = 0.3 \times 400 = 120$ volts.

Another problem of this type is illustrated in Fig. 1-21.

The following type of problem, illustrated in Fig. 1-22, serves as an excellent test to determine a thorough knowledge of the application of Ohm's law.

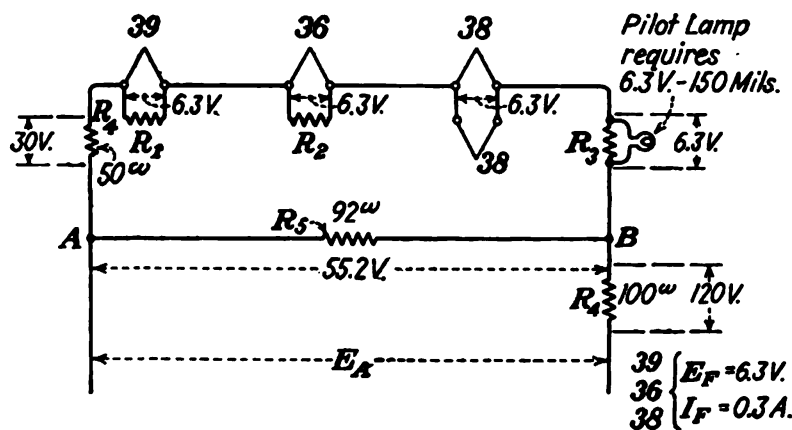


FIG. 1-22.—Series-parallel filament circuit.

On the assumption that when the proper value of voltage E_A is applied across the input terminals all tubes will receive their correct voltage and currents; how would you, with the information given, proceed to calculate the values of R_1 , R_2 , R_3 , and E_A ?

Solution: Reducing all the top branch parallel resistances to their effective values and then adding them in series from A to B, we get 92 ohms. Now since this branch

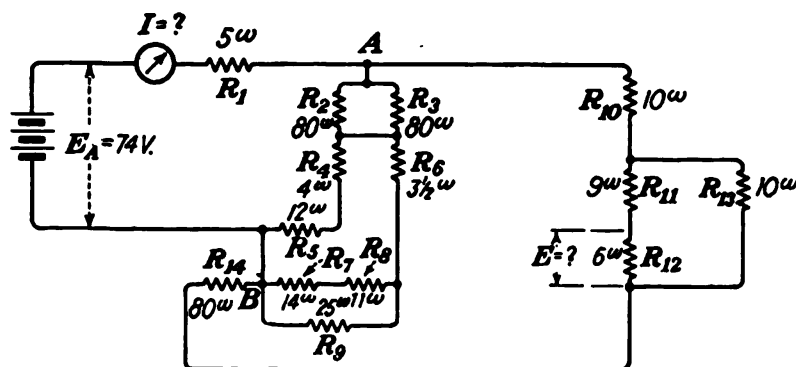


FIG. 1-23.—Complex series-parallel circuit.

is also in parallel with a fixed resistance R_1 of 92 ohms, the effective resistance of the entire combination from A to B will be 46 ohms. Thus the total resistance across the supply voltage will be $46 + 100$, or 146 ohms. Furthermore, since the current through each branch must be 0.6 amp., then the total current will be the sum of the two branches, or 1.2 amp.

Therefore if a current of 1.2 amp. is flowing through a total resistance of 146 ohms, the applied e.m.f. must be $E = IR = 1.2 \times 146 = 175.2$ volts.

Another excellent Ohm's law practice problem is that illustrated in Fig. 1-23. Here the objective is to determine the total current flow from the supply source and the voltage developed across R_{12} , the 6-ohm resistor. It is apparent that the voltage developed across this resistor cannot be calculated until the current flow through that particular branch is first determined. It is, therefore, advisable to leave this operation until the circuit has first been broken down to its simplest equivalent and the main line current flow determined.

A simple method for solving this type of problem follows:

Starting from the right and working toward the left, we see that the resistances R_{10} , R_{11} , R_{12} , R_{13} , and R_{14} are connected across the points AB and, therefore, are in parallel with the combination of resistances R_2 to R_9 . The first step will be to reduce the right arm of resistances R_{10} to R_{14} to a single equivalent value. It is important always to reduce first any parallel combination in a particular arm to its equivalent resistance. R_{11} and R_{12} are in series but also in parallel to R_{13} . Therefore, adding R_{11} to R_{12} , since they are two series resistors, we get 15 ohms. The parallel combination

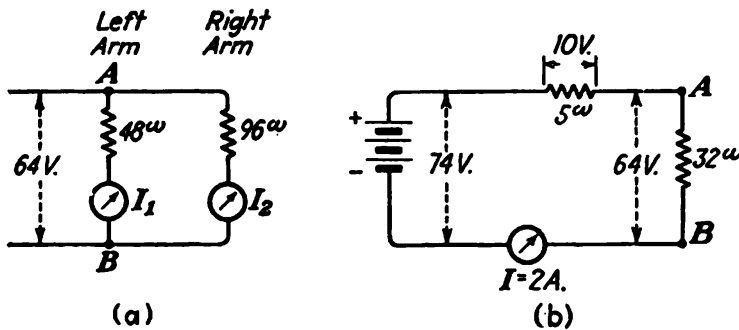


FIG. 1-24.—Equivalent circuits (see text).

of 15 ohms and 10 ohms $= \frac{R \times R}{R + R} = \frac{150}{25} = 6$ ohms. This combination is in series with resistances R_{10} and R_{14} . Thus the total resistance of the right arm from A to $B = 10 + 6 + 80 = 96$ ohms.

Now by a similar reduction of the left arm from A to B , we get R_2 and R_3 in parallel, or effectively 40 ohms; R_4 and R_5 in series, or 16 ohms, R_7 and R_8 in series, or 25 ohms. This latter pair in shunt to R_6 gives an effective value of the combination equal to $\frac{R \times R}{R + R} = \frac{25 \times 25}{25 + 25} = 12.5$ ohms. Since the effective value of R_7 , R_8 , and R_6 is in series with R_9 , the combined resistance of this branch will be 16 ohms. The combination of R_4 , R_5 being in parallel with the combination R_6 to R_9 resolves itself to an effective value of 8 ohms. Thus, since the combination R_2 , R_3 is in series with the combination R_4 to R_9 , we get $40 + 8$, or a total effective value of 48 ohms between the points AB of the left arm.

Since it has previously been found that the right arm has an effective value of 96 ohms, we find that the total effective resistance of the two arms from A to $B = \frac{96 \times 48}{96 + 48} = 32$ ohms.

The entire circuit now resolves itself to the simple equivalent illustrated in Fig. 1-24(b).

It will now be a relatively simple matter to determine the voltage developed across the 6-ohm resistance in the right arm by finding the current flow through each of the branches. Since the voltage across the both branches in parallel is equal, we find $I_1 = E/R = 64/48 = 1\frac{1}{3}$ amp.; $I_2 = E/R = 64/96 = \frac{2}{3}$ amp. Therefore, if

$\frac{2}{3}$ amp. flows through the right arm, the voltage developed across the 6-ohm resistance can be easily determined by examination of Fig. 1-25.

Proof: The sum of all the voltage drops across each of the component resistances is equal to the applied voltage at the points AB.

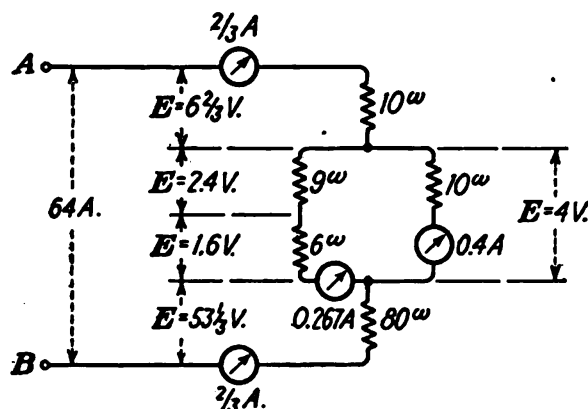


FIG. 1-25.—Equivalent circuits (see text).

1.13. Conductance.—It has been seen that the opposition offered to the flow of electrons in a circuit is called the resistance, consequently all materials possessing high-resistive properties are poor conductors; that is to say, the conductivity or conductance of such materials will be poor. Conversely, if the opposition to the flow of electrons in a material is low, the conductance is good.

The conductance of a circuit is, therefore, the reciprocal of resistance and is expressed by the ratio

$$G = \frac{1}{R} \quad (13)$$

where G represents the symbol for conductance.

Since G is the reciprocal of the resistance unit, namely, the ohm, the term conductance of a circuit is expressed as so many mhos (ohms spelled backward). For example, if a wire has a resistance of 1 ohm, the conductance will be 1 mho; if of 2 ohms resistance, $\frac{1}{2}$ mho; 8 ohms resistance, $\frac{1}{8}$ mho; $\frac{2}{3}$ ohm resistance, $\frac{3}{2}$ or $1\frac{1}{2}$ mhos, etc. If in Ohm's law, conductance is used instead of resistance the law would read

$$I = EG \quad (14)$$

$$E = \frac{I}{G} \quad (15)$$

$$G = \frac{I}{E} \quad (16)$$

1.14. Energy, Force, Work, and Power.—*Energy* may be defined as the ability or capacity to do work. *Force* is one of the factors of work and has to be exerted through a distance to do work. *Work* is reckoned as the product of the force and the distance through which it has been

applied. Work is done when energy is expended or when force overcomes resistance. *Power* is the time rate of doing work or the rate at which energy is dissipated or transferred in the circuit.

1.15. Electrical Power.—Assuming a current of I amp. flowing for a certain number of seconds t in a circuit at a potential of E volts, the amount of electricity (coulombs) flowing in the circuit would then be a result of the product of $I \times t$ in which I is expressed in amperes. From this the energy expended in the circuit is measured by the product $E \times I \times t$ and is called the *energy units* and is usually expressed in watt-hours.

The practical unit of e.m.f., the volt, is essentially made up of 10^8 units of e.m.f. called *absolute units of e.m.f.* These small units are not used in practical work but serve to indicate how certain fundamental principles are definitely concluded. Similarly, the ampere is also expressed in *absolute units of current* so that we say 1 amp., $\frac{1}{10}$ of an absolute unit of current, and hence the energy expended in heat is obtained by the equation

$$\text{Energy expended} = E \times I \times t \times 10^8 \times 10^{-1} \text{ ergs} \quad (17)$$

$$\begin{aligned} \text{Therefore, watts-seconds} &= E \times I \times t \times 10^7 \text{ ergs,} \\ \text{or Watts} &= E \times I \times 10^7 \text{ ergs per second} \\ &= \text{Energy} = E \times I \text{ joules} \end{aligned} \quad (18)$$

Hence the rate at which energy is expended in heat in an electrical circuit is obtained by the product $E \times I$. This is called the power expenditure and is referred to as so many power units, called *watts*. Thus, if an e.m.f. of 1 volt causes a current of 1 amp. to flow through a resistance of 1 ohm, the power expended in the circuit will be 1 watt; hence, 1 watt = 10^7 ergs per second. This is generally referred to as so many watts active in 1 sec. or *joules*. Thus 1 watt acting for 1 sec. is called a *joule*. Hence, a watt-hour, 1 watt acting for 1 hr. (3,600 sec.), is 3,600 joules.

$$\text{Power Expressions.}—\text{Power} = EI \text{ watts. Now, since} \quad (19)$$

$$E = IR, \quad \text{and} \quad I = \frac{E}{R} \quad (20)$$

it follows that

$$\text{Power} = I \times R \times I = I^2 R \quad \text{watts} \quad (21)$$

$$\text{or} \quad \text{Power} = E \times \frac{E}{R} = \frac{E^2}{R} \quad \text{watts} \quad (22)$$

The three expressions are numerically identical, and consequently one should use the form which is most convenient.

In saying that the three expressions are numerically identical, it must be understood that E is the voltage which forces the current through the resistance R . For example, let us assume that a current I flows between two points in a circuit. If the potential difference PD between these points is represented by E volts, then the power expenditure in that portion of the circuit will be given by the product EI as so many watts. If, however, the expression I^2R is used to denote the power expenditure, it must be understood that this equation refers only to the actual waste of power by conversion into heat. For example, if an ordinary resistance is connected across a supply voltage, all of the power is expended in heat. But, if a piece of apparatus such as a motor is connected across the voltage, some of the power is wasted in heat, while some of the power is converted into useful work. Under these conditions the product I^2R gives merely the power wasted in heat, and not the useful or working power. Hence it may be seen that as more power is wasted in I^2R less useful power will be available for the operation of the motor. Although the expression I^2R may generally be looked upon as wasted power, this is not entirely true since the power used up as heat in an electric heater is really useful power.

When mechanical work is transformed into heat or heat into work, the amount of work done is always equivalent to the quantity of heat.

1.16. Load Matching.—Perhaps one of the most important fundamentals in electrical engineering for the maximum development of power in a load is the proper design of the load device to match the resistance or impedance of the generating device itself. Whether the generating source be a generator, a chemical cell, or a vacuum tube, it must possess internal resistance or impedance. Consequently, if a load is connected to any of these generating devices, maximum power can be absorbed by the load only if the two devices are of the same resistance or impedance value.

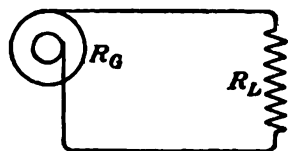


FIG. 1-26.—Circuit to illustrate load matching.

For example, let us assume the generator (R_G) in Fig. 1-26 to have an internal resistance (due to its winding) of 1 ohm. We shall assume that, at open circuit or no-load condition, the voltage developed at the terminals of the generator is 3 volts. Now, if the load resistance (R_L) is 1 ohm, the total power dissipation in the generator winding R_G and the load resistance R_L will be 4.5 watts, since

$$I = \frac{E}{R_G + R_L} = \frac{3}{1 + 1} = 1.5 \text{ amp.}$$

Hence,

$$P_{\text{total}} = E \times I = 3 \times 1.5 = 4.5 \text{ watts}$$

Each resistance, therefore, dissipates an equal amount of power or 2.25 watts. Now, if the load resistance is doubled so that $R_L = 2$ ohms, the total current flow will be

$$I = \frac{E}{R_L + R_g} = \frac{3}{1 + 2} = 1 \text{ amp.}$$

Hence

$$P_{\text{total}} = E \times I = 3 \times 1 = 3 \text{ watts}$$

The power dissipated by the load resistance, therefore, will be

$$P_L = I^2 \times R = 1 \times 2 = 2 \text{ watts}$$

and that dissipated by the generator resistance

$$P_g = I^2 \times R = 1 \times 1 = 1 \text{ watt}$$

Now, if the load resistance R_L is small compared with R_g , for example 0.5 ohm, the current flow will be $I = \frac{E}{R_g + R_L} = \frac{3}{1 + 0.5} = 2 \text{ amp.}$

Hence the total power dissipated in the two resistances will be

$$P_{\text{total}} = E \times I = 3 \times 2 = 6 \text{ watts}$$

Thus the power dissipated in R_L will be

$$P_L = I^2 \times R = 4 \times 0.5 = 2 \text{ watts}$$

while that dissipated in the generator winding R_g will be

$$P_g = I^2 \times R = 4 \times 1 = 4 \text{ watts}$$

Although a total of 6 watts is expended in the circuit, only 2 watts are available at the load. Hence, 4 watts are wasted in heat in the generator winding. This relation may be more clearly illustrated if we assume the load resistance R_L to be of zero resistance value. Under these conditions, the power available at the load points (the short-circuited resistance) would be zero, and consequently all of the power would be wasted in heat in the generator winding itself.

1.17. E.M.F. Produced by Chemical Action.—If two dissimilar substances are placed apart in certain chemical solutions, a difference of potential will be found to exist between them. Of these substances, copper and zinc, or carbon and zinc, immersed in a solution of sulphuric acid and water, constitute the most commonly used primary cells, while lead dioxide and sponge lead in a diluted solution of sulphuric acid, or a nickel-iron oxide combination in an alkali solution, constitute the two types of secondary cells.

In order to make an electric cell, it is necessary to provide two electrodes one of which is at a higher potential than the other, in consequence

of which a current will flow between these two electrodes if they are connected through an external circuit. In order to raise the potential of one electrode over the other, the two electrodes are immersed in an electrolyte which may take one of several forms. For storage batteries a diluted solution of sulphuric acid is used, while in dry cells it is a mixture of sal-ammoniac and zinc chloride. As the action of the sulphuric acid and water is the simplest to study, this action will be explained.

Let us examine the action in a primary cell (Fig. 1-27) made up of one copper and one zinc electrode immersed in a dilute solution of sulphuric acid, H_2SO_4 , the acid being dissolved in 3 parts of water.

a. When the acid is so dissolved the electrolyte breaks up into a simple positive radical or ion of hydrogen, H^+ , and a compound negative radical or ion of sulphur and oxygen (SO_4)⁻.

There is then the electrolyte in which, figuratively speaking, there are two radicals or ions in free suspension. The hydrogen ion carries a positive charge, and the sulphuric ion carries a double negative charge.

b. Owing to the chemical action of the electrolyte on the zinc electrode, atomic disintegration takes place which causes atoms to leave the surface of the zinc and combine with the negative ions (SO_4)⁻ in the electrolyte, forming zinc sulphate which dissolves in the water. During the operation of the primary cell the zinc electrode is, therefore, literally eaten away, and it is obvious that such a cell

cannot be recharged. It can be renewed by the insertion of a new zinc electrode and a renewal of the electrolyte.

c. The loss of positive charges from the surface of the zinc leaves a predominance of electrons, negative charges, and the zinc becomes negatively charged. If a circuit is provided from the zinc electrode to the copper electrode, a current will flow which will consist of a movement of the negative electrons from the zinc through the wire, over to the copper.

Hydrogen does not unite with copper (or carbon); thus the positive ions of the electrolyte are simply attracted toward the copper plate, which is negative with respect to hydrogen. This results in the formation of hydrogen gas on the plate. Here the gas clings in the form of bubbles until its lightness causes it to rise to the top of the electrolyte and escape into the air. However, under certain conditions the hydrogen bubbles do not rise rapidly enough to clear the surface of the copper electrode, and thus the *internal resistance* of the cell is increased. This formation of hydrogen gas on the surface of the positive electrode is called *polarization*, and unless counteracted, becomes a distinctly limiting factor in the life of a primary cell. To counteract polarization, oxygen must be introduced into the battery to combine with the hydrogen atom, forming water and thus preventing polarization.

d. Because of its porous nature and its ability to absorb oxygen and thus prevent polarization, carbon is preferred to copper as the positive terminal of the primary cell. The perfection of the so-called *air cell* was permitted by the discovery of a special form of carbon which literally breathes in oxygen, thus delaying polarization and making possible a primary cell with a life of a thousand hours or more.

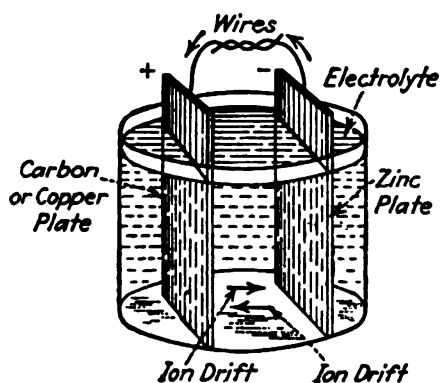


FIG. 1-27.—A simple primary cell.

e. The production of an e.m.f. in a secondary cell is essentially due to the same type of action just described for the primary cell. Planté developed the first commercially practical storage battery about the year 1860. To this day the lead-acid storage battery is essentially the same as that developed in those early days, except, of course, for mechanical improvements in making the plates and containers. The positive plate of this cell consists of a grid covered with lead dioxide, and the negative plate consists of pure sponge lead. The electrolyte is a diluted solution of sulphuric acid.

f. If an external load circuit is connected to this cell so a current can flow, the action is as follows. Oxygen atoms from the surface of the positive plate (lead dioxide, PbO_2) combine with the positive hydrogen ions, H^+ , liberated in the electrolyte, giving the plate a positive charge and leaving lead monoxide which later reacts with the sulphuric acid to form lead sulphate. The positive plate therefore becomes filled with lead sulphate as the discharge progresses.

At the same time, the negative sulphuric ions (SO_4)⁻ combine with the atoms of the negative plate (Pb) forming lead sulphate on the surface of the plate. Negative charges having been added to the surface of the sponge-lead plate to form lead sulphate, an excess of negative charges forms on the plate, and it acquires a negative charge or potential. The formation of lead sulphate on the surfaces of both plates is called *sulphation* and tends to impede the combining of the atoms of the active material of the plates with the ions liberated by the electrolyte, and the *internal resistance* of the cell is increased. As the sulphation continues, the internal resistance increases and the voltage produced drops. Lead sulphate, unlike zinc sulphate, is non-soluble in water.

g. If a current is forced through the cell in a direction opposite to the discharge current, the chemical action of discharge may be reversed, that is, the lead sulphate on the surface of the plates can be decomposed and its constituent ions forced back to their original position in the electrolyte and active materials of the plates. When all of the sulphate has been decomposed and the elements restored to their original state, the cell is said to be charged. It is obvious, of course, that the charging voltage must be greater in value than the terminal voltage of the cell; otherwise, the cell will continue to discharge and this charging voltage must be maintained at this greater value until the charging process has been completed.

The chemical action in a nickel-iron-alkali cell is very different from that of the lead-acid type; it is much more complex, but essentially the results are the same; an e.m.f. is produced owing to one plate being at a higher potential than the other. The details of this action will be described later, in the section on the Edison Cell (see Sec. 18.23).

1.18. Directions of Current Flow.—Current flow in a metallic conductor is a flow of free electrons toward the positive terminal of the conductor. In the early days of electricity it was assumed and agreed that the *conventional* flow of electric current should be a positive flow, that is, a flow from the positive toward the negative. As pointed out in Sec. 1.5 on Electric Current this conventional flow is still referred to as *the* flow of electric current whereas it is only the *conventional flow*, the actual electronic flow being in the opposite direction in the most commonly considered conductor, that is, in the metallic conductor. When the path is a gaseous one, as in certain types of vacuum tubes, the electrons liberated by electronic collision are attracted toward the positive plate or

terminal, and any positive ions are attracted toward the filament which is the negative terminal. This constitutes a flow of current in two directions: one a positive flow, and the other a negative flow; one electronic and the other consisting of positive ions. This positive flow is usually so small that it can be neglected. Its presence, nevertheless, has been proved by laboratory experiments.

The flow of current in an electrolyte consists of a flow of negative ions toward one electrode and a flow of positive ions toward the other electrode. This constitutes a flow of current in two directions, and the flow of negative electricity is not proportionately greater than the flow of positive electricity.

The directions of current flow in an electrolyte are not of much practical importance. Furthermore, as the flow of current in a vacuum tube is almost wholly an electronic flow, the positive flow, when present, can usually be neglected. In metallic conductors the flow is entirely electronic which makes it apparent that for all practical purposes *current flow is electron flow* which is always toward the positive potential.

A clear understanding of what constitutes a current flow in metallic, gaseous, and electrolytic conductors should clear up any questions as to direction of current flow. It should be understood that any statement to the effect that current flows from the positive to negative refers only to a flow in a gaseous or electrolytic conductor, or to the conventional flow of current in a conductor, in which the actual flow is electronic and, therefore, from negative to positive. Bear all this in mind when studying diagrams on which the direction of current flow in a metallic conductor (wire) may be indicated by arrows which, if pointing from positive to negative, indicate *conventional* flow, not *actual* electronic flow.

1.19. Local Action.—The presence of impurities in the plates of an electric cell sets up small local currents, owing to the action of the electrolyte on the two dissimilar metals. These impurities are embedded in the active material of the plates and may be carbon, iron, or arsenic, or other foreign matter. The local currents set up by these impurities within each plate reduce the effectiveness of the plate for its intended purpose and act as a constant drain on the cell, reducing the mass of the affected plate by actual disintegration in a primary cell or by sulphation in a lead-acid secondary cell. This waste of energy and active material is called *local action*, as it is set up locally in the cell regardless of external conditions. It is counteracted in part by using the purest obtainable material in the manufacture of the cell.

1.20. The Voltage of a Cell.—The e.m.f. produced by a cell depends only upon the kind of material used for the electrodes and the character of the electrolyte in which these electrodes are immersed. The size or shape of the electrodes does not affect the value of e.m.f. produced; but these factors do affect the capacity of the cell as will be seen later.

The voltage on open circuit is the potential difference between the positive and negative electrode. When the circuit is closed, the value of voltage is decreased by the amount of e.m.f. lost in overcoming the internal resistance of the cell and in forcing the current to flow through it. Therefore, as a dry cell gets old, and polarization increases its internal resistance, its terminal voltage drops proportionately. A voltage drop takes place also in the lead-acid cell as the plates sulphate and the internal resistance of the cell is increased.

It is for this reason that an open-circuit voltage reading is of little value in determining the potential charge in a cell. This electrical condition is, of course, affected by the *internal resistance* of the cell and must be measured under a condition which will vary with a change in the internal resistance. Such a condition is one in which a current flows through the cell, and a voltage reading is valuable only when taken with the cell discharging in a normal way.

1.21. The capacity of a cell is usually measured in ampere-hours, which may be expressed in unit form as the number of hours a cell will deliver a given current to a final terminal voltage specified by the manufacturer, and usually, on storage batteries, is indicated on the name plate.

The ampere-hour capacity of a lead-acid storage cell is proportional to the area, thickness, porosity, and arrangement of the active material, the quantity and specific gravity of the electrolyte, the temperature under which the battery is operating, and the rate of discharge. It is evident, therefore, that the ampere-hour capacity of a cell is very largely dependent upon its design characteristics.

As dry cells are not generally required to deliver much current, they are not rated in ampere-hours, although, of course, every electric cell whether a primary or secondary cell may be rated in this way if desired. In specifying dry cells it is generally more important, after the number required is known, to specify that newly made cells be supplied, as the best of dry cells deteriorate even when standing on a shelf on open circuit, and their life rarely exceeds 15 months even on open circuit. It may be said then that the capacity of a dry cell depends, in addition to the factors enumerated above, on its age.

1.22. Connection Methods.—It is evident that, other factors being constant, the voltage of a cell is dependent only on the character of the material constituting its plates, and an increase in voltage over that delivered by one cell can be had only by adding together the e.m.fs. of more than one cell. This is called *connecting cells in series* and is graphically shown in Fig. 1-28(a).

In order to increase the capacity of a battery, that is, to increase the load it can carry, it is necessary to increase the area affected by the electrolyte. As an electric cell is usually available in only a limited

number of cell sizes, it is convenient, from a practical standpoint, to increase the capacity of the battery (collection of cells), when dry cells are used, by connecting two or more cells in parallel as shown in Fig. 1-28(b). The parallel scheme is also referred to as connecting in multiple. For example, if it is said that three cells, or lamps, are connected in multiple, it is the same as saying they are connected in parallel.

It is possible by utilizing a combination of series and parallel connections to get any value of voltage or current-delivering capacity desired.

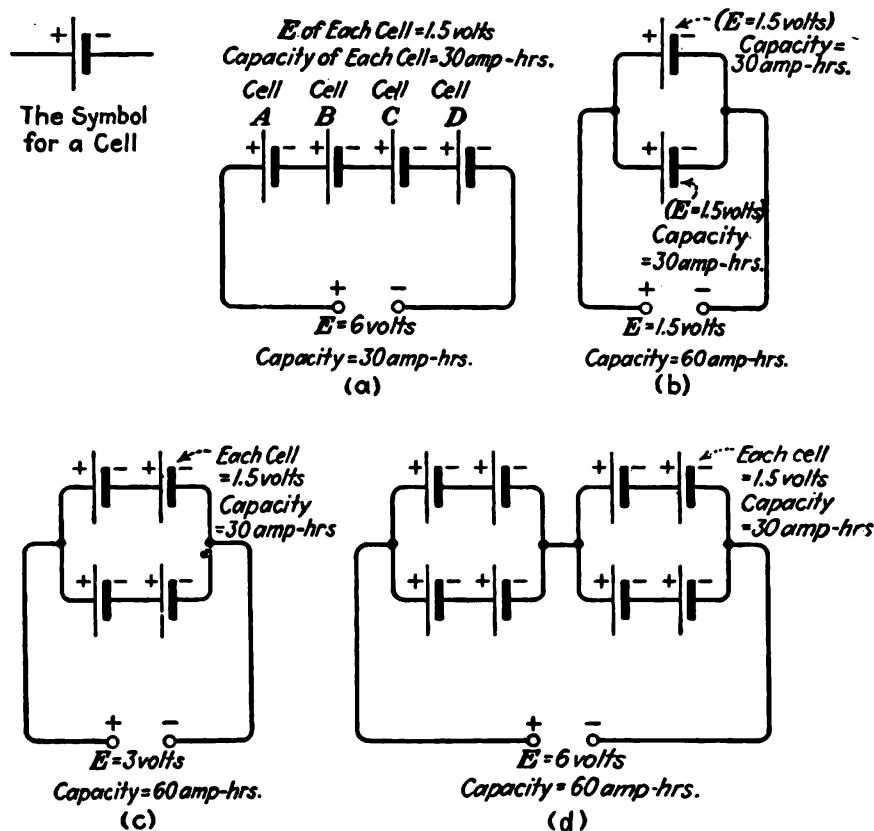


FIG. 1-28.—Various ways of connecting cells.

Such a scheme of connecting is called the series-parallel method and is shown in Fig. 1-28(c). Another series-parallel connection is shown in Fig. 1-28(d).

1.23. Internal Resistance of a Cell.—While reference has been made before in this chapter to the internal resistance of electric cells, the subject is important enough to justify this summation.

Mathematically, the *resistance* of a cell, R , is the ratio of the difference between two different voltage readings made with different loads and the simultaneous current readings made on these loads, and is expressed by the equation

$$R = \frac{E_1 - E_2}{I_2 - I_1} \quad (23)$$

I_1 and I_2 are the current readings made simultaneously with E_1 and E_2 , respectively.

Physically the *internal resistance* is the electrical resistance of the path the current must follow within the cell in flowing to one terminal of the cell or the other. This includes the resistance of the electrolyte and that of any porous electrode material. It also includes the resistance in a primary cell caused by polarization, which is an extremely variable factor being caused by the accumulation of gases on the surface of the cathode electrode, and which is accompanied by a counter e.m.f. set up by the contact of the hydrogen gas on the cathode material. In a lead-acid secondary cell it includes the resistance caused by sulphation, which is also a variable factor.

The internal resistance of a cell varies directly with the area and spacing of the active materials exposed to the electrolyte, as the cross section and length of the electrolytic conductor are thus regulated. It is obviously affected by the strength or density of the electrolyte, as the character of the conducting material is thus affected. It is also evident that the contact between the electrolyte will vary with the porosity of the active materials which accounts in part for the higher internal resistance of a discharged cell compared with a charged cell and the consequent lower voltage of the discharged cell. Finally, it varies with the temperature of the electrolyte, as the conductivity of all conductors is affected by temperature.

Summarizing, then, we may say that the internal resistance of a cell R_i acts similarly to that of any other resistance, namely, it will introduce a voltage drop or fall of potential across it. Therefore, the difference of potential or voltage across any cell or battery is the algebraic sum, or $E_s - IR_i$, where E_s = zero-current voltage, and IR_i = internal voltage drop.

We may visualize this fall of potential as being an actual loss of voltage, and it must be deducted in order to obtain the true terminal voltage of a cell. For example, let us assume that the e.m.f. of a cell under load condition 1 is 2.5 volts with a current flow of 2 amp. When load 2 is applied a current of 3 amp. flows around the circuit and through the internal resistance of the cell, and the terminal voltage falls to 2.1 volts. The internal resistance may then be computed from Eq. (23) as follows:

$$R = \frac{2.5 - 2.1}{3.0 - 2.0} = \frac{0.4}{1.0} = 0.4 \text{ ohm}$$

The voltage lost in the cell with this load is obviously $E_{loss} = IR_i = 3 \times 0.4 = 1.2$ volts. Any problem that deals with the internal resistance of a cell may be readily computed in a similar manner if these fundamentals are clearly understood.

Simplified Version of Complex Battery Problems.—Figure 1-29 illustrates a type of problem that is generally treated by Kirchhoff's laws. It is the object of this explanation to show how this type of problem may be accurately solved by simple arithmetic and Ohm's law.

The first step will be to ascertain the correct terminal voltage. This is accomplished as follows:

1. Cross multiply the internal resistances with the battery voltages, and add the products, thus, $E_1 \times R_2 + E_2 \times R_1$.

2. Divide this sum by the product of $R_1 + R_2 + \frac{R_1 \times R_2}{R_L}$, where R_L = the external load resistance. This gives the final equation, which is

$$E_T = \frac{E_1 \times R_2 + E_2 \times R_1}{R_1 + R_2 + \frac{R_1 \times R_2}{R_L}}$$

When the correct terminal voltage is obtained, it will then be possible to calculate the current flow through the external resistance R_L and each of the battery branches. In fact it will even be possible to determine the direction of the current flow through each of the branches.

The following example will serve to illustrate how this simple method may be applied to several types of problem. Figure 1-30 will serve to illustrate the various circuit conditions that may be called upon for solution.

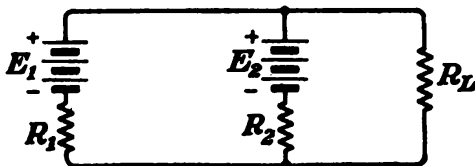


FIG. 1-29.—Complex circuit.

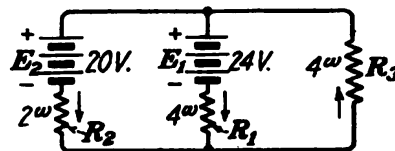


FIG. 1-30.—Complex circuit.

Solution: Figure 1-30. Cross multiplying and dividing, we obtain

$$\frac{24 \times 2 + 20 \times 4}{2 + 4 + \frac{4 \times 2}{4}} = \frac{128}{8} = 16 \text{ volts.}$$

Once the terminal voltage E_T has been found, the various branch currents may readily be ascertained by the application of Ohm's law. Starting with the current flow through the external load resistance R_L , $I_L = E_T/R_L = 4$ amp. The battery branch currents I_1 and I_2 are then calculated by taking the differences between the individual battery voltages E_1 and E_2 and the terminal voltages; thus,

$$\text{For branch 1, } I_1 = \frac{E_1 - E_T}{R_1} = \frac{24 - 16}{4} = 2 \text{ amp.}$$

$$\text{For branch 2, } I_2 = \frac{E_2 - E_T}{R_2} = \frac{20 - 16}{2} = 2 \text{ amp.}$$

In this case, it will be seen that the sum of the branch currents 1 and 2 equals the current flow through the external load. Therefore, the branch currents flowing through the batteries are in the same direction or aiding.

1.24. The Telephone Receiver and Transmitter.—*The function of the telephone receiver, or headphone, as used in radio, is to make audible the rectified high-frequency oscillations delivered by the detector or audio amplifier. Headphones used in radio work are known as the watchcase type and are constructed as shown in Fig. 1-31, which is properly labeled. A close study of the figure (b) will show clearly the component parts of this instrument. Under normal conditions the diaphragm is in position B. When a current flows through the electromagnetic coil windings, however, the diaphragm vibrates within the limits of the dotted lines A and C, depending upon whether the current in the windings at a*

given instant is aiding or bucking the effects of the permanent magnets themselves. The diaphragm is like the head of a drum, and it takes only a very slight shock to make it respond loudly. Great care must be taken not to bend the diaphragm, as this, for obvious reasons, will make the headphone inoperative. The distinctive feature of the radio headphone is that it is wound with extremely fine wire, usually No. 40 B. and

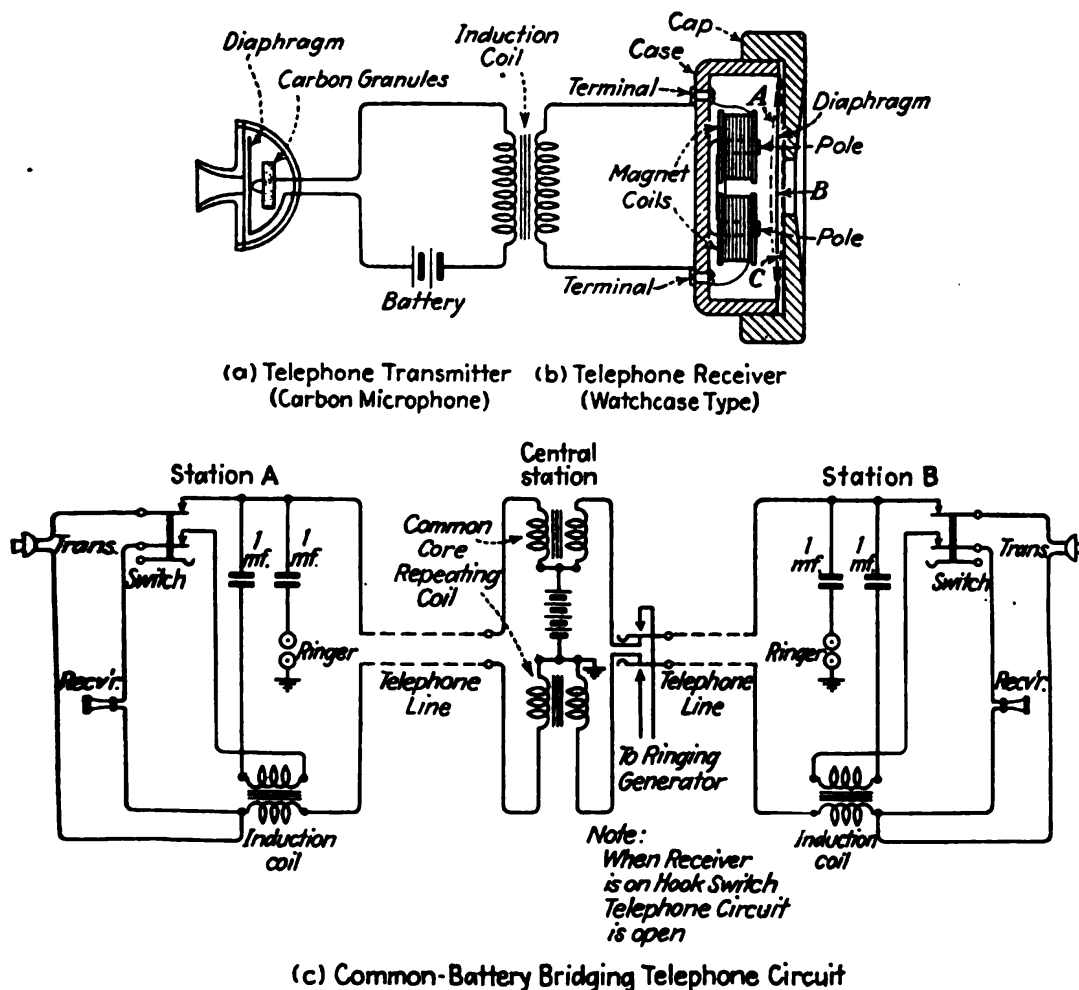


FIG. 1-31.—Telephone circuit showing construction and connection of receiver and transmitter.

S. gage, which makes it possible to get a great number of turns in a relatively small space. The m.m.f. developed by the electromagnets in the headphone depends upon the number of turns on the coil and the amount of current passing through the coil. The large number of turns results in a relatively large magnetic field being produced, even though only a feeble current is flowing. This feature makes the headphones especially responsive to weak signals. Because it is necessary to wind on so many turns of wire, the radio headphone is graded according to the resistance of its coils. The standard resistance for headphones used in commercial practice is between 2,000 and 3,000 ohms per pair. Such

phones consist of two receivers connected in series, each with a resistance of 1,000 or 1,500 ohms. There may be as many as 10,000 turns of wire used in making a headphone of this resistance. The resistance is always measured with direct current.

It is obvious that headphones will respond to audio-frequency currents only; and, even if the diaphragm were able to vibrate at the terrific speed of radio frequency, it would be above the hearing range of the human ear. The frequency to which the ordinary watchcase-type receiver will respond most strongly is called its *resonant frequency*.

Referring to Fig. 1-31, which clearly shows the component parts of a headphone of the metal-diaphragm type, it will be noted that the diaphragm is placed directly over the electromagnets. When no current is flowing through the windings of the magnets, the diaphragm is in the slightly strained position *B*, owing to the permanent magnetic field of the telephone magnets. However, when a positive alternation (for example) of current flows through the windings of the magnets, the diaphragm is drawn toward the poles to the position *A*. As soon as this alternation has passed the diaphragm springs back to position *B*. When the next alternation (negative) occurs the magnetism of the permanent magnet is neutralized and the diaphragm springs out to position *C*. As soon as this alternation has passed the diaphragm springs back to position *B*. This action is repeated for each cycle of audio-frequency current entering the headphone. The permanent magnet also prevents the diaphragm from swinging too far beyond point *B*, thus preventing rattling. For example, if a telephone receiver were constructed of a diaphragm and a simple electromagnet, no matter in which direction the current passed through the winding the diaphragm would be attracted. Hence, if an alternating current of 500 cycles passed through it, the diaphragm would be attracted once for every increase in current, or 1,000 times a second. This would obviously result in speech distortion, for, if one should talk into a transmitter at a certain frequency, then the sound in the receiver would be of higher frequency, thus producing an unfaithful signal reproduction.

This disadvantage is greatly minimized by using a permanent magnet so that the core is magnetized in one direction constantly. Hence, the diaphragm will be continually in a bent position and thus, if a current passes through the winding in one direction, it will add to the flux (magnetic lines of force) of the permanent magnet and bend the diaphragm still more. Then when the current through the winding reverses, the flux of the permanent magnet will be weakened and the diaphragm will be released somewhat from its normal position. Thus the action of the 500-cycle current will now produce a movement of the diaphragm one way on one-half cycle and the other way on the other half, and the air pulsations will then occur 500 times a second and natural-sounding speech will result.

The Carbon Microphone.—This device in the simple form used on the conventional telephone system is shown in Fig. 1-31. It operates by virtue of a vibratory diaphragm which varies the resistance of a carbon-granule button. This button is in series with the line and the induction-coil primary and, therefore, governs the current flow through the circuit. When the granules are compressed, the resistance of the button is lowered and the current in the line increased, and vice versa. The secondary of the induction coil is connected to the telephone receiver.

During normal operation, the diaphragm of the microphone varies in accordance with the frequency of the speech vibrations (waves) impinged through the mouthpiece. These vibrations of the diaphragm in turn set up varying current in the telephone line, owing to the varying resistance of the carbon-granule button, which causes a correspondingly varied e.m.f. to be induced in the secondary of the induction coil to which the receiver is connected, thereby also affecting the receiver in the same way. The frequency of the current variation in the line corresponds to the diaphragm frequency, so that a pattern of the air wave caused by the speech is reproduced in the line as an electric wave. This electric wave is again transformed into an audible air wave by the action of the telephone receiver which has already been described.

Diagram (c) shows how the magnetic type telephone receiver and carbon microphone are used in a telephone circuit in which a battery common to both stations is bridged across the line at a central station manned by an operator. The switchboard circuit at the central station is not shown.

II. MAGNETISM AND ELECTROMAGNETISM

Magnetism was one of the earliest discoveries in the field of physics which later led investigators like Faraday to study the behavior of electricity. Electrical science is built on the basic principles of magnetism, and magnetic effects are evident wherever electricity flows. A clear understanding of radio and electricity can be had only if magnetism and its effects are understood; it is a basic phenomenon which underlies the operation of many types of electrical and radio apparatus.

1.25. Natural and Artificial Magnets.—The name *magnet* was first applied to brown-colored stones possessing the peculiar property of attracting small pieces of iron or steel. Later it was found that, if a piece of such stone was suspended freely by a string, it possessed the very important property of pointing in a definite direction, very nearly north and south. It received the name *lodestone*, or *leading stone*, because of this directional property. In technical language, this material is referred to as magnetic oxide of iron, or *magnetite*. The magnetic properties or attractive forces seem to be centered at two or more points on the stone, whereas at other points no magnetic force is evident. It is called a *natural magnet* because it is found to be magnetic in its natural state and a lodestone or leading stone because it possesses the remarkable property referred to, which caused it to be used for navigation.

All magnets used in the construction of electrical apparatus and machinery are *artificial* magnets, that is, they must be made magnetic by some process. Hereafter in this text, when a magnet is referred to, an artificial magnet is meant.

Magnets may be divided into two classes, namely, temporary magnets and permanent magnets. The class into which a magnetic material falls depends upon its molecular structure. Most temporary magnets are made of soft iron (steel), and most permanent magnets are made of a hard-steel alloy. For practical purposes, a temporary magnet is one that quickly loses its magnetism after the magnetizing force is removed, and a permanent magnet is one that retains its magnetization over a long period of time after the original magnetizing force is removed, although eventually it too may lose its magnetic property and need to be remagnetized. Both types are extensively used in radio and electrical apparatus.

If a piece of steel such as a darning needle is stroked in one direction with a piece of lodestone, it will be found to be magnetized. This can be proved by the fact that it will attract iron filings, a compass needle, or any other small piece of magnetic material. If this needle is now used to stroke a second needle, the second needle will be magnetized, and so one magnet may be used to produce another magnet. This is a common laboratory demonstration, but for practical purposes this method is useless, and magnets used in electrical apparatus are produced by electromagnetic means. This method is fundamentally simple and means that a magnetic material such as iron or steel is surrounded by turns of wire through which an electric current is made to flow. In this way, the magnetic material is magnetized. Electromagnets will be more fully discussed later in this chapter.

1.26. Poles of a Magnet.—The ends of a magnet are termed its *poles*. The end that points to the north geographical pole is generally called the *north-seeking pole*, and is usually marked on one end of the magnet by an N; the other end is called the *south-seeking pole* and is marked S.

The term *magnetic polarity* refers to the nature of the magnetism at a particular point on the magnet, or in other words, whether it is a north- or a south-seeking magnetism.

Magnetic Attraction and Repulsion.—If a steel bar which has been

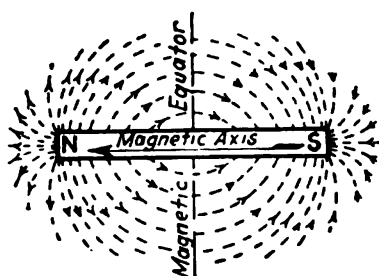


FIG. 1-32.—Poles of a magnet, and magnetic field.

magnetized is suspended at the center by a silk thread and placed in the vicinity of a north or a south magnetic pole, it will tend to swing parallel with the magnetic field created by the pole.

Figure 1-32 illustrates the magnetic lines of force emanating from the *north* pole and entering at the *south* pole through the air medium. The lines of force then return to the *north* through the magnet, thus completing its field.

If the bar is carefully marked at one end for reference, it will be noted that one particular end will always point in a definite direction. This is due to the polarity effect of one magnetic field upon another. No matter how many times the bar is turned by hand, it will always return to its original magnetic position. Figure 1-33(a) and (b) illustrates the magnetic effect of two magnetic fields, one upon the other. Figure 1-33(a) shows how the lines of force tend to combine and thus attract the two bodies, whereas Fig. 1-33(b) shows the “bucking” or repelling effect of the fields and, hence, a repulsion of the two bodies. This holds true

with all magnetic bodies. Whenever two *north* poles or two *south* poles are placed near each other, they will tend to repel one another. On the other hand, if poles of *north* and *south* polarity are placed in the same vicinity, they will attract each other owing to the combining effect of the magnetic fields.

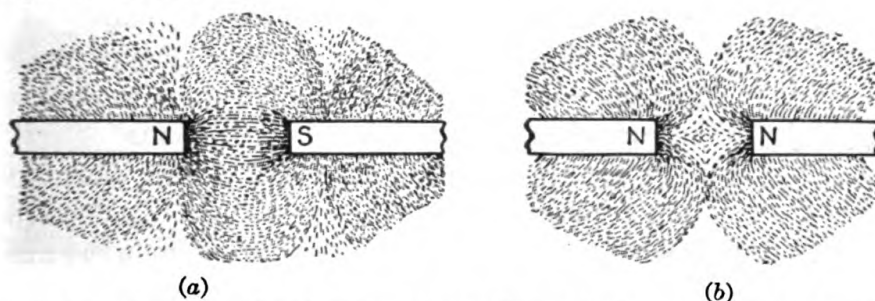


FIG. 1-33.—Magnetic effect between; (a) unlike, and (b) like, poles of a magnet.

If the strength or distance between the magnets is varied, the effect will vary accordingly.

This gives us the laws of magnetism which are:

1. *Unlike poles attract one another: like poles repel one another.*
2. *The force between two magnetic poles varies inversely as the square of the distance between them and is proportional to the product of their strengths.*

The second law is not strictly true because it assumes that each pole is a point or dot. It is true enough for practical purposes, however, provided the poles of the magnet are not too close to one another and are long in proportion to their cross-sectional areas.

1.27. Magnetic Fields.—Various forms of magnetic bodies possess certain magnetic advantages. Of these forms the two most important are the bar magnet and the horseshoe magnet.

Figure 1-34(a) illustrates the magnetic-field arrangement of a horseshoe magnet. Compare this with the field arrangement of the bar magnet in Fig. 1-32. Note that the concentration of the lines of force in Fig. 1-34(a) is much greater than in Fig. 1-32. This is obviously due to the shorter air path through which the lines of force travel and, hence, results in a lower amount of magnetic leakage. Therefore the strength of the magnetic field at the poles of a horseshoe magnet would be considerably stronger than that of a bar magnet. If it is desired, however, to decrease the magnetic leakage of the horseshoe to a still lower degree, then a small iron bar may be placed across or between the poles as illustrated in Fig. 1-34(b).

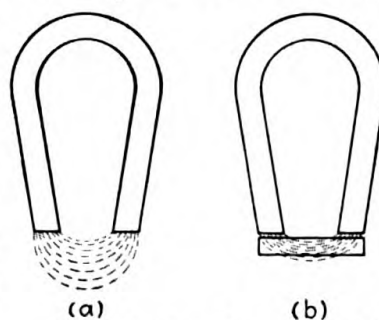


FIG. 1-34.—Magnetic field arrangement of a horseshoe magnet.

Whenever a low-loss magnetic circuit is required, the magnetic material may be formed into a closed magnetic path by arranging it into

a horseshoe, circular, or rectangular form with a small air gap between the poles.

The ring magnet (Fig. 1-35) provides a complete metallic path for the magnetic field. As the magnetic path is continuous, this magnet has no poles. If the ring is broken at any point, a north and south pole will immediately be produced at the ends. A transformer core is an example of a ring-type magnet in rectangular form. The ring magnet is also used in certain electrical indicating instruments.

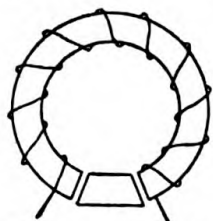


FIG. 1-35.—The ring magnet.

Characteristics of Flux Lines.—Flux lines have certain characteristic tendencies which may be stated as follows: they are continuous throughout the magnetic circuit and form closed lines which never cross; they act like stretched rubber bands, tending to shorten themselves while at the same time a stress exists which tends to keep each line separate from its neighbor; the magnetic field at any point is the resultant of all of the lines acting on that point.

1.28. Magnetic Transparency and Leakage.—If a magnet were placed in a position to deflect a magnetic needle, and if a non-magnetic substance, such as glass, wood, brass, or rubber, were placed between the needle and the magnet, the lines of force would complete their circuit through the non-magnetic body, as shown in Fig. 1-36(a). If a piece of iron were interposed between the magnet and the needle, however, the iron would act as a *magnetic screen* and reduce the needle deflection toward the magnet, as shown in Fig. 1-36(b).

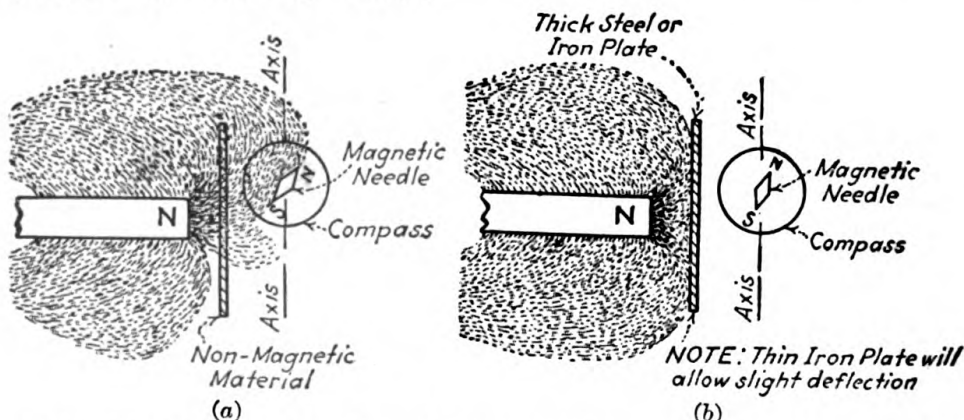


FIG. 1-36.—(a) Non-screening effect of non-magnetic material; (b) screening effect of magnetic material.

It is seen then that a magnetic material may be used to screen off a magnetic field. This screening effect is due to the lower reluctance of the magnetic screening material which causes the magnetic lines to take the easiest path through the magnetic screen.

In electrical machines and instruments, the magnetic field is designed to act on certain windings and so produce a specific effect. Only those

lines of force or that flux which so acts as intended may be called *effective flux*. A certain amount of flux is always lost in the surrounding space, although this loss may be kept small if desired. The flux which is lost and is therefore ineffective is said to be lost through *magnetic leakage*. Magnetic leakage may be desirable under some conditions and undesirable under others.

1.29. Theory of Magnetism.—Although magnetism has been studied for over a century, no satisfactory theory has yet been evolved to explain all magnetic phenomena. There is, however, a mass of disconnected facts, many of which lend themselves readily to the evolution of a theory of magnetism.

Modern theories of magnetism, such as they are, are primarily due to the basic work on magnetism done by Prof. P. Curie of radium fame. It is logical that Curie's work on magnetism and radium should be so closely interrelated, as modern science now recognizes the relationship of the two fields of research.

Recent research has uncovered the fact that the atom, in addition to being made up of electrons and protons, contains a third component part called *electromagnetic energy* which it gives off in the form of radiation under certain conditions. It is this released energy which is now thought to be the cause of magnetic effects. This belief has grown out of the modern theory of magnetism which attributes magnetic phenomena to the rotation of electrons inside the atoms of magnetic substances.

The *electron theory of magnetism*, which seems to be the most acceptable of all magnetic theories thus far advanced, depends on the existence of magnetons, which in magnetic terminology and structure are equivalent to the electron in electrical terminology and structure. Just as an atom contains electrons so does it contain magnetons, so many to each atom, depending on the material. These magnetons are, in effect, magnetic forces which make of each atom an elementary magnet.

In an unmagnetized material it is supposed that the magnetic forces, the elementary magnets within a molecule, are directed in all directions in a promiscuous fashion as indicated in Fig. 1-37(a). When magnetism is induced into the material, it is supposed that each molecule becomes polarized owing to a reorientation of the atoms within the molecule, so that the magnetic forces within all the molecules are directed in the same direction [see Fig. 1-37(b)].

Weiss, a noted investigator of magnetism, claims an extra or intrinsic field in addition to the individual atomic magnets, and that to this molecular field must be attributed the action of forces, neither magnetic nor electrostatic, whose nature is still unknown. Perhaps this unknown force may prove to be that component of the atom now known as *electromagnetic radiation*.

If a material is placed in a magnetic field in air, the lines of force will either be closer together or farther apart as they pass through the

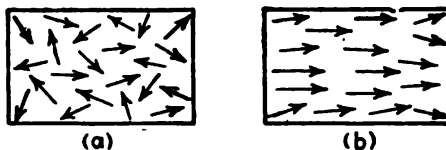


FIG. 1-37.—Polar arrangement of atoms in a molecule. (a) Unmagnetized material; (b) magnetized material.

material. If the lines are farther apart, the material is known as a *diamagnetic* material or, if closer together, as a *paramagnetic* material. Iron, and materials of which iron is a divalent, nickel, and cobalt are classed together and are called *ferromagnetic*. Ferromagnetic materials are, therefore, a kind of paramagnetic material. Owing to the action of the lines of force on the magnetic material, a magnet will repel slightly a diamagnetic material and attract slightly a paramagnetic material, unless it is a ferromagnetic material in which case it will attract it strongly.

Tin, zinc, silver, copper, gold, and lead are a few of the diamagnetic materials. All iron alloys, nickel, and cobalt are ferromagnetic, and all other magnetic materials are simply classed as paramagnetic. This sums up to the fact that all materials less magnetizable than air are called diamagnetic; and all materials more magnetizable than air are called paramagnetic. Nearly all magnetic materials with which the electrical or radio engineer has to deal are of the ferromagnetic class.

Langevin, another authority on magnetic research, states in effect that substances whose atoms have their electrons in revolution in such a way that their effects are additive are paramagnetic and that the atoms of such substances may be looked upon as elementary magnets.

The spacing of the atoms within the molecule seems to play a very important part in magnetic phenomena. This is evidenced by the effect of heat on a magnetic material. Heat increases the space between the atoms and decreases magnetism.

*Magnetostrictive effects*¹ cannot as yet be explained by the theories thus far outlined. Simple orientation of the molecules would not explain a change in the physical dimensions of a ferromagnetic bar unless it is assumed that the molecules take up more room when oriented a certain way. But this theory seems to fall down when it is considered that an increase in magnetizing force may cause the material both to expand and to contract.

Magnetic theory in its present status is far from settled, and new ideas are continually being advanced. Some day, science may evolve a satisfactory theory to explain *all* magnetic effects, but until then the present hypothesis called the *electronic theory of magnetism* will serve for most purposes.

1.30. Magnetic Variables.—A magnet may lose its magnetism if subjected to a physical shock. The amount of magnetism lost will depend upon the severity of the jar. A new magnet will lose a greater percentage of magnetism than an old magnet, if both are subjected to the same shock. Any piece of apparatus, such as a meter or telephone receiver, containing a permanent magnet should be carefully guarded against rough usage.

A magnet will lose its magnetism upon being heated to a bright-red heat. Lesser heating will cause a magnet to lose a proportionate amount

¹ See Magnetostriction Effect, Sec. 1.32.

of its magnetism. If a permanent steel magnet is placed in hot or boiling water, its magnetic strength will be reduced, although it will be partly recovered when the magnet cools off. Chilling a magnet increases its magnetic strength.

Constancy of magnetic strength in a magnet is by no means permanent. When a permanent magnet is first magnetized—when it is being made—it is found that the magnetism consists of stable and unstable magnetism. The unstable magnetism must be removed, before the magnet is put to practical use. Even the stable magnetism decreases with the age of the apparatus. Every physical shock, every contact the magnet might make with iron, every change in temperature, all these factors tend to weaken its magnetism until eventually its magnetism becomes dissipated below a useful degree and the magnet must be remagnetized. Remagnetization of the magnets in a direct-current generator is sometimes necessary to replace residual magnetism.¹ It is frequently necessary to remagnetize the permanent magnets in radio telephone receivers, especially the lower resistance types.

1.31. Purpose of Pole Pieces.—Only those lines of force from a permanent magnet which traverse the windings of a meter or rotating machine are useful lines of force. Normally the field between the poles of a magnet consists of straight lines of force as shown in Fig. 1-38(a). A con-

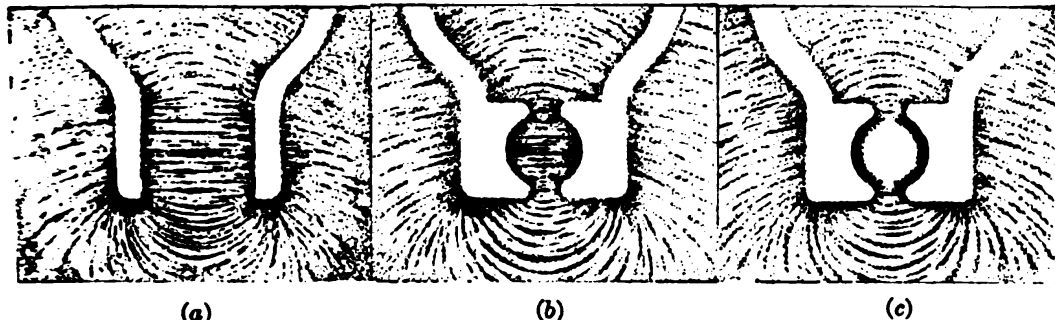


FIG. 1-38.—Magnetic field between the poles of a magnet. (a) Normal field; (b) concentrated field; (c) radial field due to armature. (Courtesy of Weston Electrical Instrument Corporation.)

centration of these lines of force is desired so that the field will be confined where it will be most effective, and a more uniform field maintained throughout the armature windings. This field concentration may be accomplished by fitting pole pieces to the poles of the magnet resulting in a field as shown in Fig. 1-38(b). The ideal position of the lines of force between the pole pieces is radial, like the spokes of a wheel. With this condition the lines of force cut the armature windings at a uniform angle throughout their entire revolution. The effect of the field on the windings is then more uniform, and better operating results are obtained

¹ *Residual magnetism* is the magnetism left in a material after the magnetizing force has been entirely removed.

from a unit section of the field. This is accomplished when the armature core is placed between the pole faces. For a two-pole meter, the field is as shown in Fig. 1-38(c). For a multi-pole generator, the field is as shown in Fig. 1-39. Note that the lines of force are parallel to the radius of the core and are therefore radial.

It is to be noted also that the curved faces of the pole pieces, fitting closely around the armature, reduce the air gaps between the pole faces and the armature to a minimum, thereby reducing stray magnetic losses to a minimum.

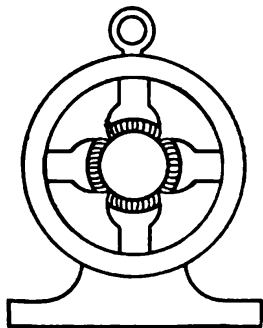


FIG. 1-39.—Radial field produced in generator by armature.

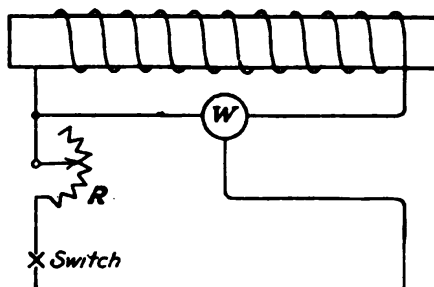


FIG. 1-40.—Diagram to illustrate magnetostriction effect.

1.32. Magnetostriction Effect.—To illustrate the magnetostriction effect, suppose first an unmagnetized steel bar is inserted within a solenoid connected to a source of e.m.f., the resistance R is at a maximum value, and the switch is open (see diagram, Fig. 1-40).

If the switch is now closed, a reading will be observed on the wattmeter indicating power in the electromagnet. If a direct-reading micrometer-indicating instrument were attached to measure the length of the bar, it would be found that when the bar was magnetized by the field from the solenoid it would contract a few millionths of an inch. If the value of the resistance is now decreased, an increased power will be noted on the wattmeter. The bar will now return to its original length owing to the increased magnetic effect. The bar has thus far completed one alternation of physical vibration.

If the value of R is still further decreased, allowing more power into the electromagnet, the bar will contract its length. This contraction and expansion continue as long as the state of magnetism in the bar is varied, and at a rate depending upon the physical dimensions of the bar and the magnetic material used.

The conclusion drawn from this experiment is that a change in magnetic condition causes a change in physical condition in the bar. This is called the *direct* magnetostriction effect.

Another magnetostriction effect has been observed which is the reverse of the direct effect just described. This effect is that a bar of magnetic material whenever it is subjected to a mechanical stress will change its magnetic state. This effect is generally called *indirect* magnetostriction.

Now, if the steady e.m.f. applied to the electromagnet is replaced with an alternating e.m.f., the frequency of which is resonant with the

vibration period of the rod, the distortioning effect on the rod may be increased 100 times.

1.33. Fields around Conductors.—The normal position of the electrons and protons in a wire before the application of a potential may be visualized as a number of positive and negative charges with their electrical forces acting upon one another. The negative forces about the electrons and the positive forces about the protons being equal, there will be no exterior effect on the outside of the wire. Even the movements of the free electrons in conducting materials produce no exterior effects on the outside of a conductor because they move relative to each other in all directions with equal velocity and consequently their average vector velocity is zero.

If, however, a difference of potential is applied to the conductor, the free electrons in the conductor will be displaced in a certain direction, depending upon the polarity of the applied e.m.f. This results in a progressive drift of the electrons along the conductor, with their forces combining to form a unidirectional force which acts at right angles to their progressive motion. This condition is illustrated in Fig. 1-41 in which an electron is displaced from left to right. Thus, if a number of free electrons in a conductor are moving progressively from left to right, an exterior manifestation of the displaced electric fields will result. This external field is called the *magnetic field* and is the theoretical basis of operation of all dynamo-electrical machinery.

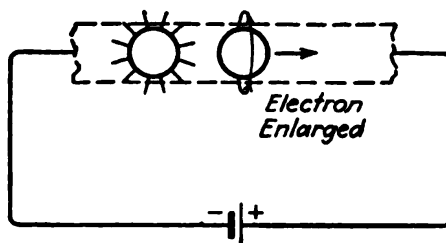


FIG. 1-41.—Movement of an electron in a wire.

Figure 1-42 illustrates the magnetic field around a conductor carrying current. It will be seen that the electrons are moving toward a point of high potential (+) and that their motion results in a magnetic field in a given direction. It is important to note at this point that the direction of the exterior magnetic field is entirely dependent upon the progressive motion and the direction of the electrons in the conductor. For

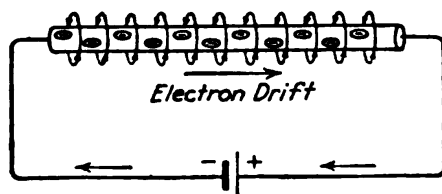


FIG. 1-42.—Electron drift in a conductor.

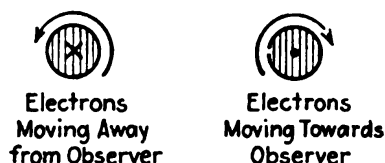


FIG. 1-43.—Magnetic field around a conductor.

example, if the electrons are moving along a conductor away from the observer, the magnetic field will be in a counterclockwise direction, and, if the electrons are moving toward the observer, the direction is clockwise. This condition is illustrated in Fig. 1-43 and may be permanently remembered by using the left hand as a rule. The thumb points in the direction in which the electrons are flowing (toward the positive

potential); and the fingers indicate the direction of the magnetic lines of force (see Fig. 1-46).

In all practical circuits the magnetic field is looked upon as a separate entity, but in reality it is always associated with an electric field. It is therefore convenient to look upon a magnetic field around current-carrying conductors as the manifestation of forces (magnetic) evoked by the movement of an electric field (electrons in motion).

Since each electron in motion contributes a proportionate share of the current flow in the conductor, it can readily be seen that the greater the number of electrons which are in progressive motion, the larger will be the current flow, or amperes, in the conducting circuit. Furthermore, since each electron in progressive motion also contributes its external magnetic forces (magnetic field), the greater the number of electrons moving along the conductor, the stronger will be the magnetic field. Each electron in motion may be pictured as possessing a magnetic line of force and, since there are a great number of electrons in motion through a conductor, the exterior magnetic field will possess more lines of force or a stronger magnetic field.

The presence of a magnetic field about a conductor carrying current may readily be determined by placing a magnetic needle or compass in the vicinity of the conductor, as illustrated in Fig. 1-44. When the circuit

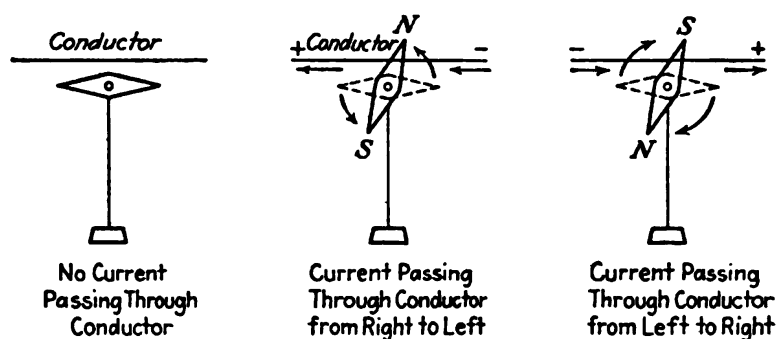


FIG. 1-44.—Effect of magnetic field on a compass needle.

is closed and the electrons are caused to flow in the direction of the arrows, the needle will tend to turn at right angles to the conductor; but, if the flow is turned off, the needle will resume its original position. The force which made this needle turn at right angles to the conductor was composed of the lines of force, or magnetic field, produced by the progressively moving electrons in the conductor. The magnetic field is thus definitely proved to be in a right-angular position because it was in this direction that the needle turned when placed in the vicinity of the field.

Now, since the direction of a magnetic field about a conductor carrying current is definitely known, it is possible to determine the effect of these fields upon one another in accordance with the fundamental laws of attraction and repulsion of magnetic bodies in the vicinity of one another. For example, if two conductors are placed side by side and are carrying current in the same direction, the magnetic forces will also be in the same direction, or supplementary, which will cause the combining of the fields into one larger and consequently stronger magnetic field as shown in

g. 1-45(a). If the current flow in adjacent conductors, on the other hand, is in opposite directions, then the magnetic forces will oppose or neutralize each other and may actually result in the complete cancellation of the exterior effectiveness of the magnetic fields, as shown in Fig. 1-45(b).

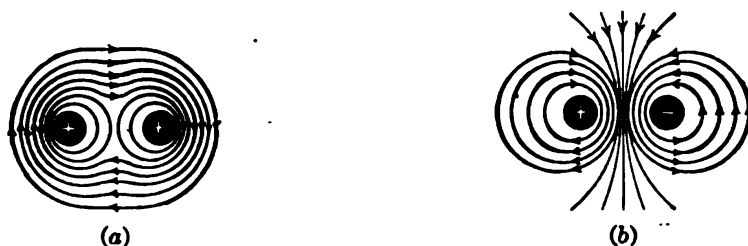


FIG. 1-45.—Effect of (a) supplementary and (b) opposing fields in adjacent conductors.

The strength of a magnetic field around a conductor may be greatly increased by forming the wire into a coil or solenoid, thereby causing the lines of force around each wire to interlink or combine with the adjacent or succeeding turns.

The magnetic field through a coil of this kind is similar to that of an ordinary bar magnet in that the lines of force all concentrate in the center or axis of the coil and *leave* and enter at the magnetic poles. The strength of the magnetic field around a coil may be greatly increased by inserting an iron core or bar of soft iron therein.

Thus it can be readily seen that the strength of a magnetic field around a coil or solenoid may be increased by one or more of the following methods:

- a. Increasing the electron flow (current) through a conductor.
- b. Increasing the number of turns on the coil.
- c. Increasing the diameter of the coil.
- d. Increasing the flux density by inserting an iron core.

Left-hand Rules.¹—Several simple rules have been devised to aid in remembering the relationship between the direction of the magnetic lines of force and the electron flow. Figure 1-46 illustrates an easy way to remember and determine the direction of the magnetic field around a conductor if the direction of the electron (current) flow is known. The conductor is grasped as shown, the thumb pointing in the direction of the electron flow. The fingertips then point in the direction taken by the lines of force as they build up and surround the conductor.

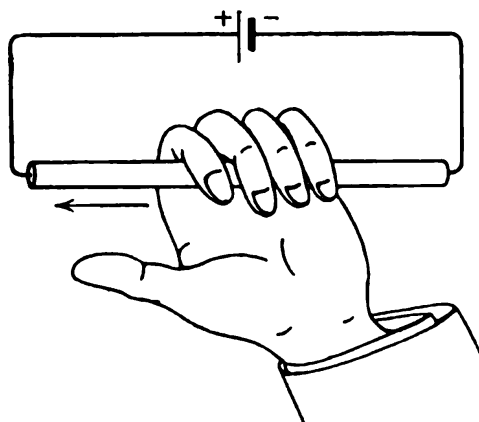


FIG. 1-46.—Finding the direction of the magnetic field in a conductor by the left-hand rule.

¹ Based on the fact that the electron current flows from negative to positive.

The magnetic polarity of a coil or solenoid may be determined in a similar way as shown in Fig. 1-47. With the left hand, the coil is grasped so that the fingers point in the direction of the electron flow. The thumb will then point in the direction of the north pole of the magnetic field.

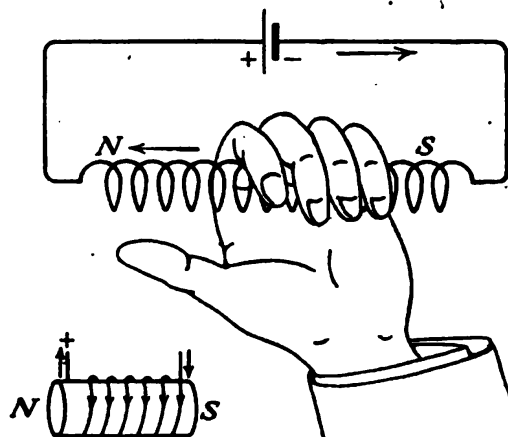


FIG. 1-47.—Finding the direction of the magnetic field in a solenoid by the left-hand rule.

1.34. Induced Currents.—Faraday discovered that, if a closed-circuit conductor such as a coil was moved in the vicinity of a magnet, a current would flow in the circuit. He followed this up later by the discovery that a varying current in one conductor would cause a current to flow in a second conductor, provided the second conductor was brought close enough to the first one and a continuous path provided for the current to flow in. Such currents are said to be generated by *induction* and are called *induced currents*. The combined action of induction and current flow is termed *electromagnetic induction*.

Electromagnetic induction is thus responsible for the operation of all electric generators and motors, and, when this phenomenon is used for this purpose, it is termed the *dynamo-electrical effect*. Electromagnetic induction is also responsible for the transference of electrical energy from one closed circuit to another and when so used is termed the *transformer effect*.

Law of Induction: 1. When an *e.m.f.* is induced in a closed circuit by a conductor cutting a field, or vice versa, the amount of current flow is proportional to the rate of cutting and the number of linkages.

2. The induced *e.m.f.* sets up a current the direction of which tends to prevent a change in the number of linkages.

The above statements, which are proved to be true, have been summarized by Lenz into a law known by his name which substantially concludes as follows: An induced *e.m.f.* always sets up a magnetic field the direction of which is such as to oppose any change in the force (field) which produces it.

1.35. Production of E.M.F. by Field Cutting Conductor.—A current flow can be set up in a conductor by moving it through a magnetic field.

Figure 1-48 illustrates this fundamental action. A permanent magnet is placed so that a conductor can be moved in front of its pole faces. A sensitive zero-center galvanometer is connected to the ends of the conductor to indicate the e.m.f. induced. If the conductor is started above the north pole in the position *A*, shown by the dotted lines, and swung down in front of the north pole, a deflection will be noted on the galvanometer. This deflection will be, let us say for the sake of illustration, toward the positive sign on the scale. The value of e.m.f., as shown by the meter, will be a minimum at the start of the movement and maximum as the conductor passes

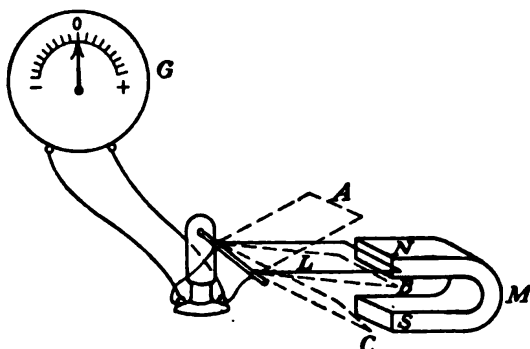


FIG. 1-48.—Experimental set up for the production of an e.m.f. by a field cutting a conductor.

directly in front of the pole face, returning to minimum at position *B* which is the point where the conductor passes from the field coming out of the north pole and enters the field going into the south pole.

As the direction of the field in relation to the conductor is reversed as the conductor continues its journey, and begins to pass the south pole, the induced e.m.f. will be reversed and will be so indicated on the galvanometer which will swing over toward the negative sign on the scale. The value of induced e.m.f. will follow the same general pattern of rising from zero to maximum and back to zero again as it passes in front of the south pole just as it did when passing the north pole, the only difference being in the reversal of the induced e.m.f.

If the conductor is swung upward from position *C* to position *A*, currents will be induced in the conductor, and they will be in the same order to what they were when the conductor was swung downward as before explained. The galvanometer would indicate this condition by swinging first toward the positive and then toward the negative as the conductor passed first the south pole and then the north pole.

If the conductor is moved slowly across the front of the magnet, the deflection on the meter will be relatively small, whereas, if the conductor is moved quickly through the magnetic field, the deflection on the meter will increase.

If the flux in the magnetic field is increased by utilizing a winding around the magnet and making it an electromagnet, the deflection on the meter will be greatly increased. The increase in induced e.m.f. will be proportional to the increase in the field flux.

Another way to increase the induced e.m.f. would be to utilize more than one turn of conductor. Two turns will cause twice the deflection on the meter that one turn will cause, everything else being equal. It is apparent, then, that the more turns there are, the greater the induced e.m.f.

From this experiment we are able to deduce certain fundamental laws governing the generation of a current by the dynamo-electrical

effect, namely: (1) whenever there is a relative movement between a conductor and a magnetic field, an e.m.f. is induced in the conductor; (2) the polarity of the e.m.f. induced in the conductor depends upon the direction of the relative motion between the conductor and the magnetic field; (3) the intensity of the e.m.f. produced in the conductor depends upon the intensity of the magnetic field and the speed of the relative motion between the conductor and the field; (4) the value of the induced e.m.f. varies directly with the number of turns in the conductor.

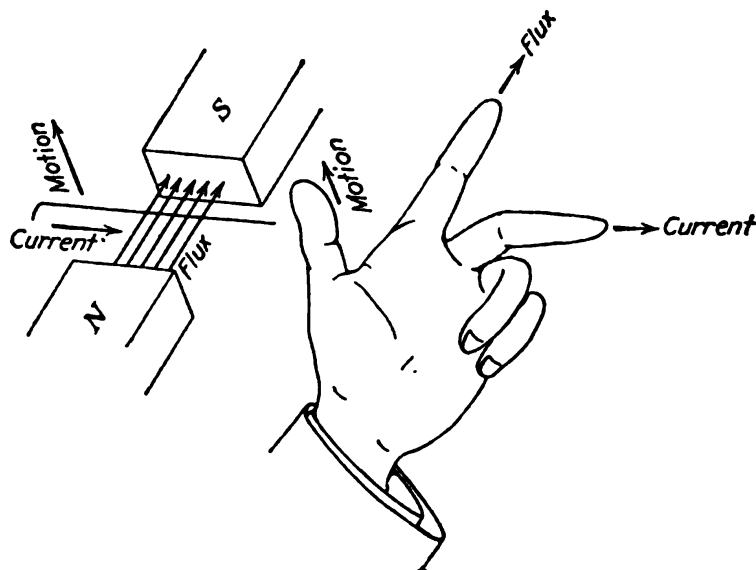


FIG. 1-49.—The left-hand generator rule (according to the electron theory).

Left-hand Generator Rule.—A rule that will give the relation between direction of flux, motion, and direction of electron flow is stated below. *Point the forefinger of the left hand in the direction of the flux, the thumb in the direction of motion; the middle finger will point in the direction of the electron flow in the metallic circuit.* This rule is illustrated in Fig. 1-49.

III. THE MAGNETIC CIRCUIT

1.36. The magnetic circuit is similar to the electric circuit in that in it is provided a force of a unit quantity which overcomes a unit resistance. In the electric circuit these factors are measures of e.m.f., current, and resistance, whereas in the magnetic circuit they are represented by m.m.f., flux density, and reluctance. An Ohm's law of the magnetic circuit may, therefore, be drawn up as follows:

$$\text{Flux} = \frac{\text{m.m.f.}}{\text{reluctance}}$$

a. *Flux* is the total number of lines of force making up the magnetic field. The symbol for flux is ϕ , pronounced phi.

b. *Magnetomotive force* (m.m.f.) is comparable to electromotive force in that it is a force producing a certain phenomena. It is represented by

the letter F . The unit of measure of m.m.f. is the *gilbert*, and 1 gilbert is equal to 1.26 times the number of turns times the current flowing in the circuit or,

$$F = 1.26 \times N \times I \quad (24)$$

c. Reluctance is that property of a material which opposes the creation of a magnetic flux in the material. It is the "resistance" of the magnetic circuit or the counter force in the magnetic circuit which the magnetic field must overcome. The symbol for reluctance is the script letter $\mathfrak{R}$, and the most commonly accepted unit of reluctance is the *oersted* which is the reluctance of 1 cc. of air.

Reluctance may also be expressed in *rels*. A material has a reluctance of 1 rel when an m.m.f. of 1 ampere-turn generates in it a flux of one line of force. *Ampere-turns* = $N \times I$, where N is the number of turns and I is the current in amperes.

d. Reluctivity is a measure of *specific reluctance*, which may be expressed in oersteds per cubic centimeter or rels per cubic inch. If the c.g.s. (centimeter-gram-second) system is used, the reluctivity of all materials including air, but excepting iron and steel and their alloys, is 1 oersted. If measurement is made in cubic inches, 0.313 rel is used as the specific reluctivity figure for air, instead of 1 oersted. The symbol for reluctivity is ν , the Greek letter nu.

Reluctance, like resistance, varies inversely with the area, and directly with the length, of the path. For a given magnetic circuit the reluctance is

$$\mathfrak{R} = \frac{\nu l}{A} \quad (25)$$

where ν is specific reluctance in oersteds or rels, l is the length of the magnetic circuit in centimeters or inches, and A is the area or cross section of the magnetic path in centimeters or inches. If ν is in oersteds, l and A must be in centimeters; and if ν is in rels, l and A must be in inches.

e. Magnetic and Non-magnetic Materials.—Although all material is magnetic to a certain extent, it is customary to refer to all matter including air, but excepting iron and steel and its alloys, as non-magnetic. Iron and steel and its alloys are referred to as magnetic materials.

1.37. Ohm's law equivalent for magnetic circuits is summarized as follows:

$$\phi = \frac{F}{\mathfrak{R}} \quad (26)$$

$$\mathfrak{R} = \frac{F}{\phi} \quad (27)$$

$$F = \phi \mathfrak{R} \quad (28)$$

where ϕ = flux, F = m.m.f. in gilberts, and $\mathfrak{R}$ = reluctance in oersteds.

If F is expressed in ampere-turns, $\mathcal{R}$ is usually in rels. Ampere-turns may be changed to gilberts by multiplying by 1.26 which then gives $\mathcal{R}$ in oersteds.

1.38. Magnetic-circuit Computations. *a. The Gauss.*—In order to reduce the labor involved in making magnetic-circuit computations, it was found necessary to provide tables and curves of magnetic characteristics of certain materials. To make these curves and tables practical, it

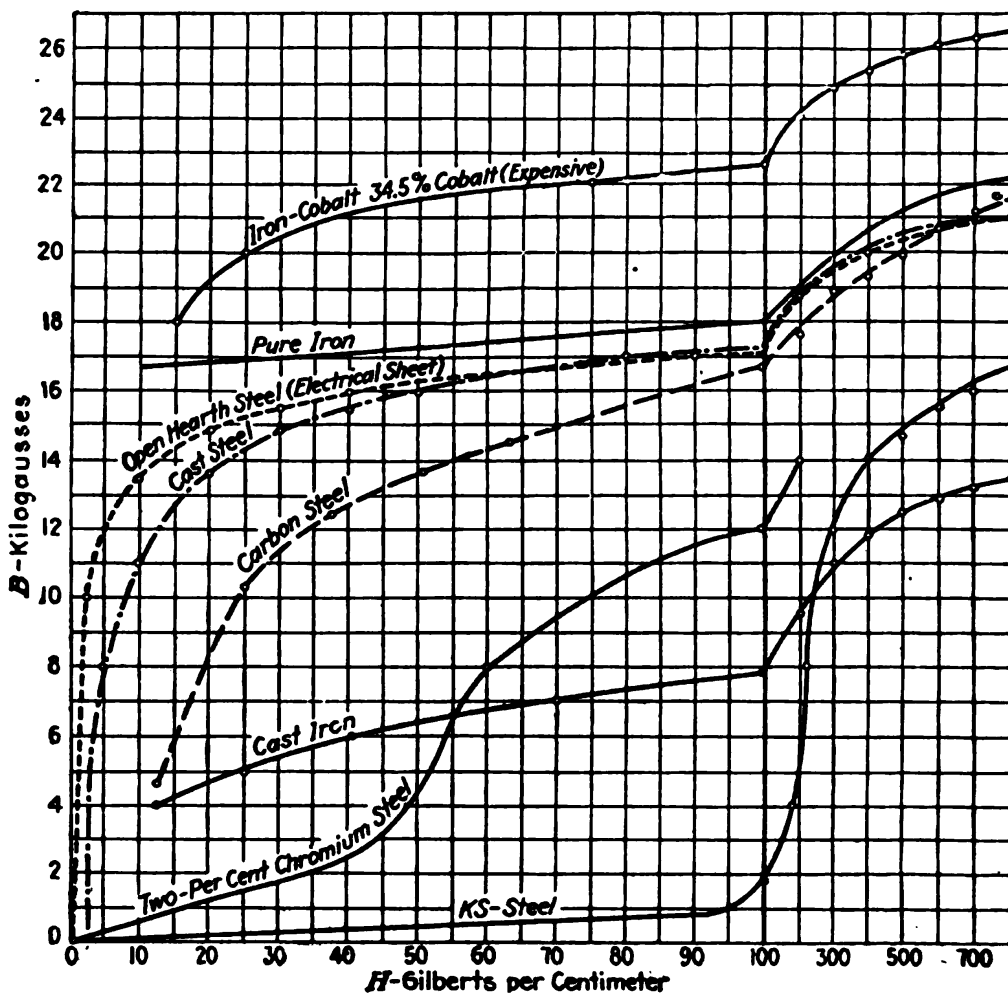


FIG. 1-50.—Typical $\mathcal{B}$ - $\mathcal{H}$ curves

was necessary to express flux and m.m.f. in definite units. Flux, therefore, in a magnetic material is referred to as *flux density* and is expressed in *gausses per square centimeter* or *lines per square inch*. A gauss may be defined as *one line of force*.

For practical purposes, the expression gauss means lines of force per square centimeter. If gauss is given in square centimeters, the m.m.f. necessary to produce this flux is given in gilberts per centimeter. If flux density is given in lines per square inch, then m.m.f. is given in ampere-turns per inch.

The symbol for flux density is $\mathfrak{B}$, gaussses per square centimeter (or B , meaning lines per square inch).

Another value which must be used in magnetic-circuit calculations is that of the m.m.f. involved. This factor is expressed in gilberts per centimeter necessary to produce a given flux density. The symbol for gilberts per centimeter is the script $\mathcal{H}$, or H ampere-turns.

b. $\mathfrak{B}$ - $\mathcal{H}$ Curves.—A magnetization curve may be drawn showing the relationship between m.m.f. and flux density for a specific unit of material. Such curves are known as $\mathfrak{B}$ - $\mathcal{H}$ curves. A set of these curves for various common magnetic materials is shown in Fig. 1-50. A typical curve for permalloy, which is commonly used in high-grade audio transformers, is shown in Fig. 1-51.

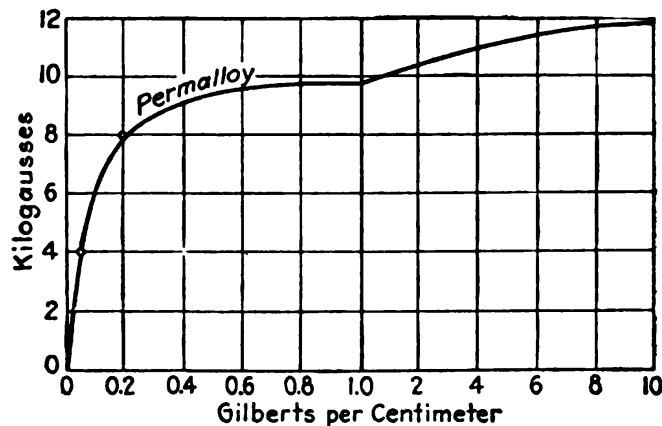


FIG. 1-51.— $\mathfrak{B}$ - $\mathcal{H}$ curve for permalloy.

As the designing engineer is interested in practical units, H is usually given in ampere-turns. If $\mathcal{H}$ is given as gilberts, the answer in ampere-turns may be secured by dividing by 1.26. $\mathfrak{B}$ - $\mathcal{H}$ curves are very useful in figuring magnetic computations.

Example: Suppose a transformer is to be designed having an electrical sheet-steel core with a cross-sectional area of 4 sq. cm. It is necessary to produce a flux of 60,000 lines in the core. The length of the magnetic path is 28 cm. How many ampere-turns are required to produce this flux?

Formula:

$$\mathfrak{B} = \frac{\phi}{A} \quad (29)$$

Solution:

$$\mathfrak{B} = \frac{60,000}{4} = 15,000 \text{ gaussses} = 15 \text{ kilogausses}$$

By referring to the curve (Fig. 1-50) for electrical sheet steel, it is found that to magnetize this material to a flux density of 15 kilogausses requires 22 gilberts per centimeter. For this path of 28 cm., 22 must be multiplied by 28, giving 616 gilberts required. Dividing by 1.26 gives 489 ampere-turns required.

c. Permeability is the comparable unit of measurement showing the ease with which a magnetic field may be set up in a material as compared with air. It may be expressed in the formula

$$\mu = \frac{\mathfrak{B}}{\mathcal{H}} \quad (30)$$

where μ is the permeability, $\mathfrak{B}$ is the flux density expressed in gaussses or lines per square inch, and $\mathcal{H}$ is the m.m.f. in gilberts per centimeter, or ampere-turns per inch. Therefore,

$$\mathcal{H} = \frac{\mathfrak{B}}{\mu} \quad (31)$$

and

$$\mathfrak{B} = \mathcal{H}\mu \quad (32)$$

d. Saturation.—When the molecular rearrangement of the magnetic material has been completed by the magnetizing force, a material is said to be saturated. Flux density may be increased beyond the saturation point, but the m.m.f. necessary to do this will be much greater proportionately after saturation than before saturation, and the circuit is not efficient. Inasmuch as this is true, it is practically assumed that the saturation point marks the limit of magnetization.

e. Reluctance of Magnetic Material.—While the reluctance of non-magnetic material is constant at 1 oersted per cubic centimeter, or 0.313 rel per cubic inch, the reluctance of magnetic materials varies over a wide range dependent upon the material and the m.m.f. involved. For example, while the reluctance of gray cast iron is such that with an m.m.f. of 100 gilberts a flux density of 8,000 gaussses may be produced, at 200 gilberts the reluctance has changed so that 9,600 gaussses is produced. Using certain kinds of wrought-iron forgings, 100 gilberts will produce 16,500 gaussses; whereas 150 gilberts will produce almost 18,000 gaussses. To ascertain the relative reluctance of a certain magnetic material, reference may be made to permeability or induction tables or curves found in electrical engineering handbooks.

f. Remanence is a measure of the magnetism left in a material after the magnetizing force has been entirely removed and the material left in a free state. This remainder is also called the *residual magnetism*. The property of a magnetic material which makes it possible to acquire residual magnetism is called *retentivity*.

1.39. Hysteresis is a lagging of magnetizing effect behind magnetizing cause, a lagging of $\mathfrak{B}$ behind $\mathcal{H}$. This may be understood by referring to the hysteresis loop or magnetic cycle shown in Fig. 1-52. Imagine a piece of iron which has not been magnetized and which is now to be magnetized. The curve *a-b* shows the magnetization characteristic as the m.m.f. is

applied. If, when point *b* is reached, the magnetizing current is reduced, the iron will commence to become demagnetized. The flux density in the iron will become less as the m.m.f. is reduced until point *c* is reached where the applied m.m.f. is zero. It is to be noted that the flux density has not dropped to zero with the m.m.f. As a matter of fact, a considerable amount of residual magnetism, or remanence, is still present in the iron owing to the retentivity of the iron. This residual magnetism, therefore, is represented by the ordinate *a-c*. As the cycle continues, a negative m.m.f. is applied; but 4 gilberts of negative m.m.f. must be

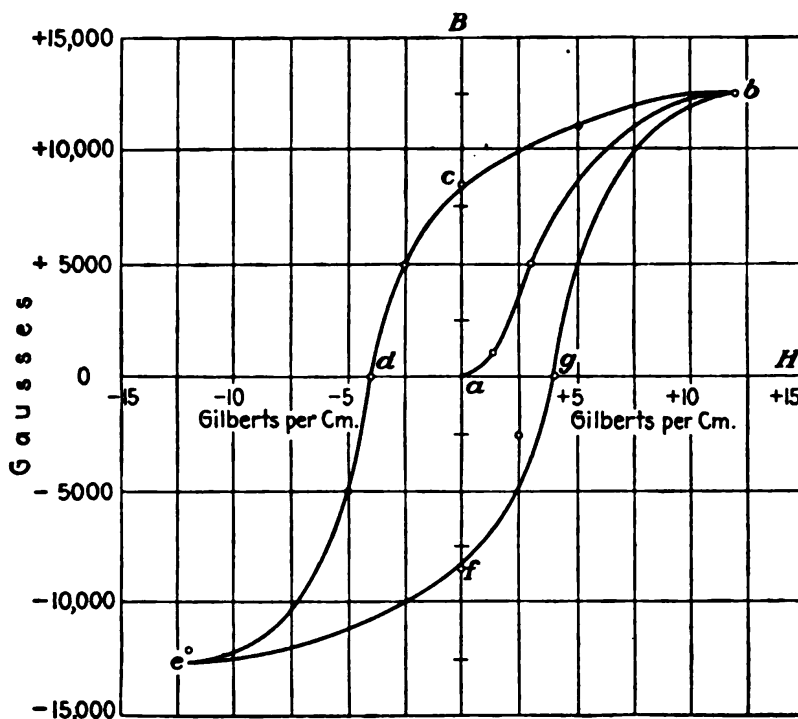


FIG. 1-52.—A typical hysteresis loop.

applied before the iron is demagnetized. This power, which is necessary to nullify the residual magnetism, is called the *coercive force* and is a distinct loss of power. It is a hysteresis loss and may be figured and allowed for as such.

If the negative m.m.f. is increased beyond *d* to a negative value numerically equal to its positive value, the flux density will increase to the point *e* which will equal the density at *b*. If the m.m.f. is now decreased, the same action will be repeated from point *e* to point *f* as took place from point *b* to *c*. As the m.m.f. is now applied in a positive direction the same action takes place, but in the opposite direction, from the point *f* to point *b* as from the point *c* to point *e*. The hysteresis loop or magnetic cycle is now completed. The energy lost through hysteresis is proportional to the area of the hysteresis loop and manifests itself as heat.

CHAPTER 2

ALTERNATING-CURRENT ELECTRICITY

Although most electrical currents are in themselves movements of electrons along a wire, the characteristics and effects of these currents become complex if the direction or magnitude of these currents is changed in any way. Usually changes in electrical circuit constants and characteristics are due to the effects of alternating current, and it is the purpose of this chapter to explain these effects and their causes.

In alternating-current circuits, the electrons do not actually traverse a circuit progressively but oscillate to and fro owing to the constantly changing polarity of the applied e.m.f.

I. ALTERNATING-CURRENT GENERATION AND TRANSFORMATION

2.1. The Alternator Principle.—Generators of alternating current are usually known as *alternators* and are theoretically the simplest type of dynamo-electrical machines. Basically an alternator may be equivalent to an electromagnet and a moving conductor, an e.m.f. being induced in the conductor by its movement through the magnetic field.

A simple illustration of the alternator principle is shown in Fig. 2-1, in which a conducting loop *ABCD* is arranged in a position so that it can be rotated on its horizontal axis in the air space between the two poles of a magnet, *N* and *S*. The loop has an outlet to two slip rings and brushes from which the alternating e.m.f. and current can be drawn for external use.

It has already been shown in the preceding chapter how an e.m.f. may be induced in a conductor by causing it to cut a magnetic field. With this theory in mind we may proceed to the analysis of the generation of an alternating current by an alternator.

Position I (Fig. 2-1) is the starting point of the rotation movement of the loop, and, incidentally, represents the neutral position of the loop with respect to the field from *N* to *S*. At this instant, the sides of the loop are moving in a direction parallel to the lines of magnetic flux, and the induced e.m.f. is zero as shown in the curve.

Position II shows the loop after it has revolved through an angle of 90 degrees during which time it has cut a certain number of magnetic lines of force and has induced in it an e.m.f. which in turn creates a current flow in the conductor in the direction *ABCD*. This current flow is regarded as positive in the graphical illustration and is indicated by the curve being drawn above the line of zero voltage.

Position III shows the loop passing through the 180-degree region of its revolution in which position it is again parallel with the magnetic lines of force (flux), and for this instant no e.m.f. is being induced as is shown by the curve.

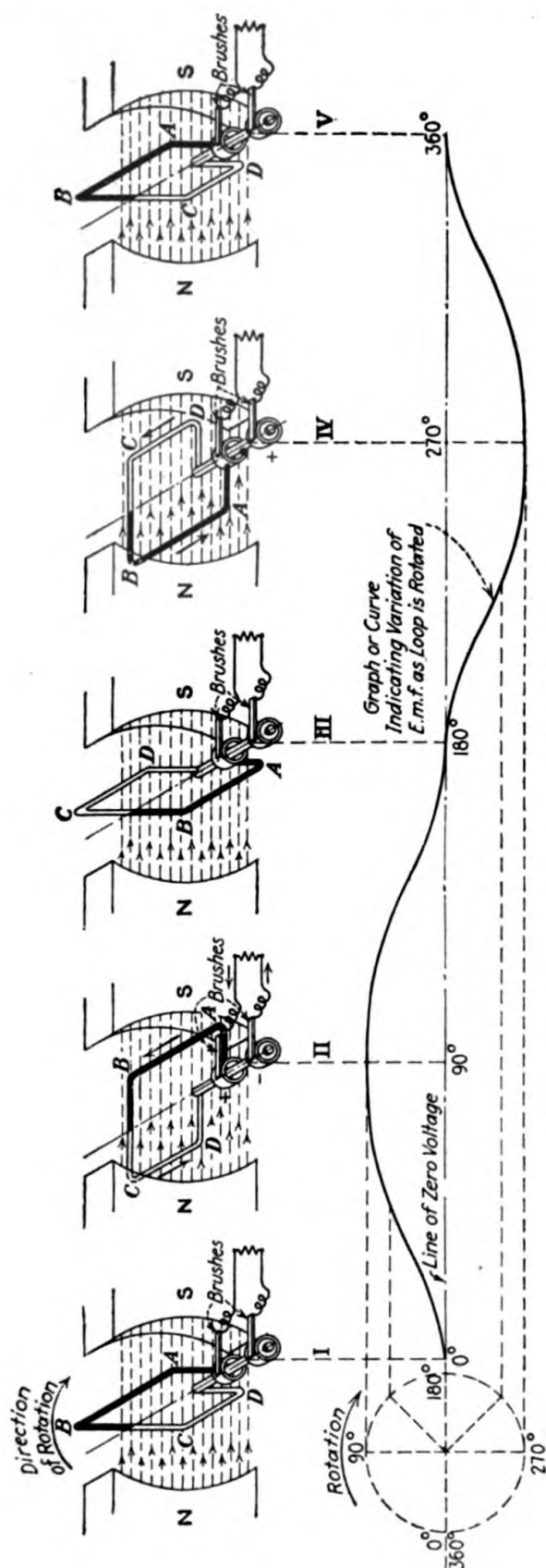


FIG. 2-1.—A simple illustration of the alternator principle.

Position IV is the 270-degree region of its revolution in which the conductor is once more cutting the field with the resultant current flow as shown by the curve. It is to be noted here that the sides *AB* and *CD* have completely reversed their position; that is, side *AB*, which was at the south pole in position II, is now at the north pole of the magnet. Therefore, the e.m.f. which has been generated in the loop during the first half of the revolution has now changed its direction, and is now indicated below the zero line of the curve.

Position V shows the loop as it is completing its revolution and is again parallel with the magnetic flux, the condition under which no e.m.f. is induced in the conductor. Sides *AB* and *CD* are now again in their starting positions, and, if the loop is again rotated in the same direction, another complete cycle of e.m.f. will be generated.

Any change in the direction of rotation, speed, or number of turns in the conductor, or in the strength of the magnetic field, will directly affect the value of the generated e.m.f.

Cycle and Frequency.—It is now evident that during the 360-degree revolution of the loop two alternations of current have taken place and flowed in the external circuit *R*. These two *alternations* of current constitute one *cycle* of alternating current, and the number of cycles per second is termed the *frequency* of the current.

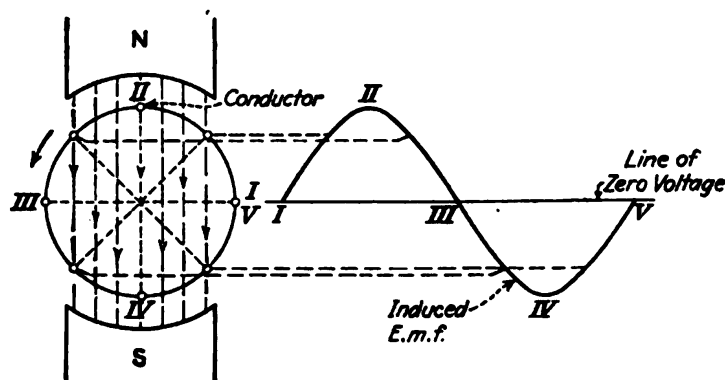


FIG. 2-2.—The angular relation between an armature conductor and the current it produces in an alternator.

Thus, an alternator is a machine for generating alternating current, or, in other words, a current which reverses its polarity periodically. The angular relation between the conductor and the cycle of current it produces is shown in Fig. 2-2.

2.2. Principles of the Transformer. *a. General Considerations.*—It has been shown that, if a moving magnetic field is developed in a coil by passing an alternating current through it, the moving field may be used to induce an e.m.f. into a near-by circuit, provided that the two circuits are magnetically related and in the proper axial positions. This condition is illustrated in Fig. 2-3(a) and is the fundamental theory upon which all transformers operate.

The transformer consists essentially of two separate coils of wire insulated from each other and wound upon a laminated iron core. The

winding which is connected to the alternating-current source is called the *primary* and that into which an alternating e.m.f. is induced is called the *secondary*. If it is desired to increase the voltage developed across the secondary winding relative to that impressed across the primary winding, the number of turns in the secondary must be more than those in the primary winding. This is called a *booster* or *step-up transformer*. If, on the other hand, it is desired to develop a lower voltage across the secondary winding than is put into the primary, then the number of turns in the secondary winding must be less than those in the primary. This is called a *step-down transformer*.

The transformation of voltage from low to high or vice versa is entirely dependent upon the turn ratio between the windings and not upon the size or character of the iron core. The core serves to complete the interlinkage of the magnetic lines of force between the two windings so as to insure the maximum transfer of energy (power) from one circuit to the other. The magnetic lines of force which do not interlink are called *leakage flux*. The greater this leakage, the greater will be the losses and consequently the lower the efficiency. Other losses also contribute greatly to the inefficiency of transformers, namely, core losses and copper losses.

Core losses are due to the generation of heat in the core material produced by the molecular friction of the molecules when an alternating e.m.f. is applied to the core winding. These reversals introduce a power dissipation which represents an energy waste and takes away from the useful contribution of power from one circuit into another. These losses are known as *hysteresis* and *eddy currents*.

Hysteresis may be reduced to a minimum by the use of special core material such as silicon steel or permalloy, in which the molecular friction is known to generate a minimum of heat. The losses may further be reduced by using the proper physical dimensions of core material to insure against hot operation. Hysteresis losses are illustrated by the hysteresis loop shown in Fig. 1-52.

Eddy currents are electrical currents set up in the core material by the magnetic field. These currents manifest themselves as a heat or I^2R loss in the core material. Eddy currents are minimized by constructing the core of laminated pieces of magnetic material and by insulating each piece from its neighbor, usually done by covering each piece with an insulating varnish before assembly.

Copper losses are reduced by the use of the proper size of wire to accommodate the input- and output-load conditions without overheating.

b. Operating Conditions.—When the primary winding of a power transformer is connected to the alternating-current line, the value of the current flow in the primary winding will be affected by the value of the current flow in the secondary. If the secondary winding is operating

under zero load, or on open-circuit conditions, a voltage will be developed by the secondary winding depending upon the ratio of turns, but no power will be developed in the winding. Hence the value of the current flowing in the primary circuit under no-load conditions is equal to $I = E_{eff}/Z$.¹ Actually, under these conditions, the current flowing in the primary winding will be very small owing to the fact that the voltages induced into both coils (self-induction) are in opposite directions. These induced voltages are, as a matter of fact, very nearly equal to the applied e.m.f.

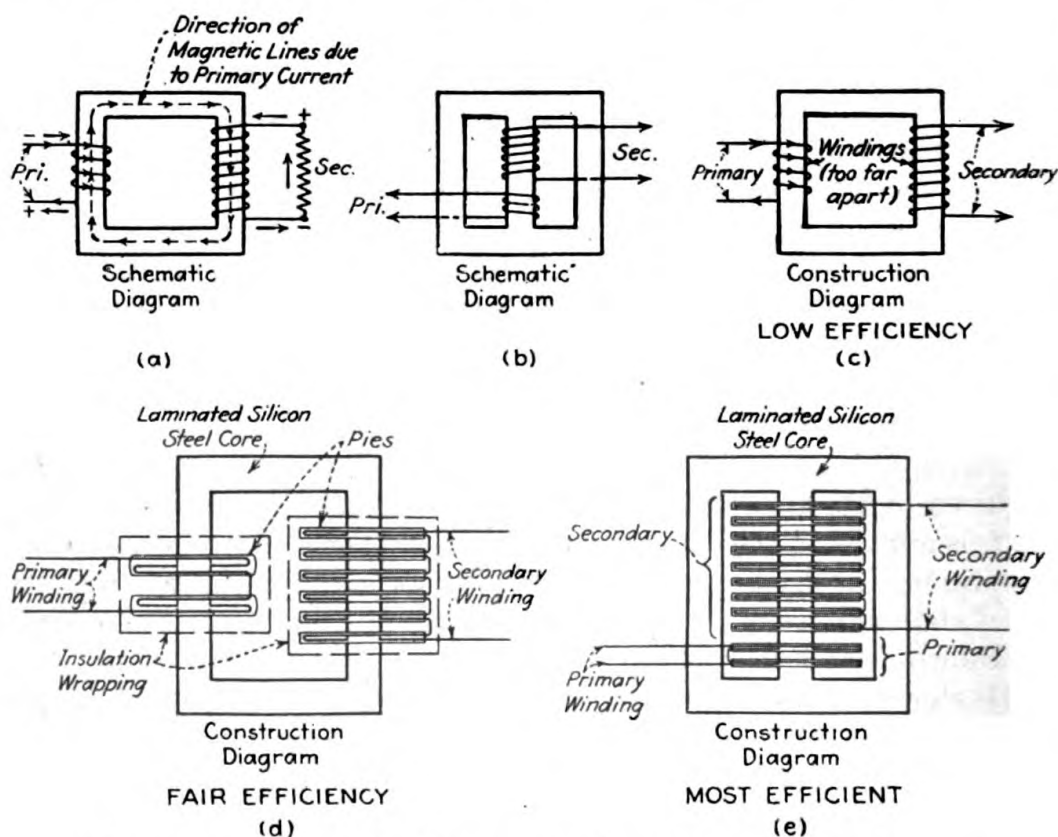


FIG. 2-3.—The electrical and constructional principles of the transformer.

Another way of looking at the circuit conditions when the secondary is unloaded is that very nearly all of the magnetic energy developed in the magnetic field around the primary winding is returned to the supply circuit, and consequently very little power is lost.

Under loaded secondary conditions, however, the result is quite different. When the secondary circuit is closed, a current will flow in the winding which will develop a magnetic field about it. This field is 180 degrees out of phase with that produced by the primary winding, and consequently acts to oppose it, owing to the secondary voltage being 180 degrees out of phase with the applied primary voltage.

¹ The effective voltage E_{eff} is that which exists owing to the difference between the applied E_1 and the counter e.m.f.

Assuming that the counter e.m.f. is constant for all values of load, that is, neglecting the small primary IR drop, it follows that the flux in the transformer which produces this counter e.m.f. must remain constant for all values of load. When current is drawn from the secondary the flux thus set up tends to decrease the total flux, and therefore, the current in the primary must increase so as to add the same number of ampere-turns to the magnetic circuit as are being subtracted by the current in the secondary. This concept leads directly to the relation between primary and secondary currents and number of turns, since the ampere-turns in each case, neglecting the magnetizing current, must be the same.

Moreover, there are lines of force present around the primary winding which do not interlink with the secondary. The same is true around the secondary. Now, since these lines in the respective windings do not react upon one another, consequently they cannot neutralize each other. This tends to maintain a certain amount of reactance in both the primary and secondary windings, and in effect is the same as if two additional reactance coils were connected in series with the primary and secondary circuits, respectively. Although this does tend to reduce the possibility of overloading the windings it is imperative to maintain the reactance as low as possible to obtain a constant potential at variable loads, or, in other words, to improve regulation.

Now, since magnetic-leakage reactance represents lines of force which do not interlink with their associated windings, it is merely necessary to place the windings very close together to insure a maximum degree of mutual (M) inductance or coupling. This may be obtained by arranging the primary and secondary windings as illustrated in Fig. 2-3(b). Figure 2-3(c) illustrates the arrangement of the two windings which results in high-leakage reactance and poor voltage regulation.

In transformers where high set-up voltages are desired, the close proximity of the high-voltage winding to the exciting winding necessitates careful insulation to prevent voltage breakdown. This is generally accomplished by distributing the strain between turns through a sectional arrangement of the windings into layers or "pies," as illustrated in Fig. 2-3(d) and (e). Each pie is thoroughly insulated from the adjacent one by mica or micarta insulations, and the individual pies are wrapped in specially treated empire cloth or insulating wrapping. All the pies are then connected in series to obtain the desired turn ratio between the windings.

c. Voltages, Current, and Power Relations.—In an ideal transformer the voltage ratio developed between the primary and secondary circuits equals the turns ratio N between the two windings, namely,

$$N = \frac{E_s}{E_p} = \frac{N_s}{N_p} \quad (1)$$

The current I_p , flowing in the primary circuit under load conditions will be

$$I_p = I_s \times \frac{N_s}{N_p} \quad (2)$$

and consequently, the secondary voltage E_s that is developed under load conditions will be

$$E_s = \frac{N_s}{N_p} \times E_p \quad (3)$$

Practical working formulas for any condition may thus be evolved from the preceding and following formulas:

$$E_p = \frac{E_s \times I_s}{I_p} \quad \text{volts} \quad (4)$$

$$I_p = \frac{E_s \times I_s}{E_p} \quad \text{amperes} \quad (5)$$

$$E_s = \frac{E_p \times I_p}{I_s} \quad \text{volts} \quad (6)$$

$$I_s = \frac{E_p \times I_p}{E_s} \quad \text{amperes} \quad (7)$$

Since the transformer is a device which transfers energy from one circuit into another, it is evident that the power which can be dissipated in the secondary winding with 100 per cent efficiency would be exactly the same as that flowing in the primary. Thus,

$$P_p = P_s \quad \text{watts}$$

However, since energy is lost in the heating effect of the wire I^2R , and core losses are present owing to eddy currents and hysteresis, the power output in the secondary circuit cannot be equal to that which is put into the primary. The efficiency is obtained by taking the ratio of the power output P_s to the power input P_p ; thus,

$$\text{Efficiency per cent} = \frac{P_s}{P_p} = \frac{\text{output}}{\text{output} + \text{losses}} \times 100 \quad (8)$$

Furthermore, since the active power (P) expended in an alternating-current circuit is $P = E \times I \times p.f.$, then by applying this product to the transformer circuit we get ($p.f.$ = power factor, see Sec. 2.22)

$$P_p = E_s \times I_s \times p.f.(s) \quad \text{watts} \quad (9)$$

$$P_s = E_p \times I_p \times p.f.(p) \quad \text{watts}$$

Hence, neglecting losses, $P_p = P_s$.

It may thus be seen from the various relations that the transformer may be designed for high-voltage or low-voltage outputs by merely obtaining the correct turns ratio between the two windings. The size of the wire has no bearing upon the voltage output. Hence, if it is desired to step up the voltage between the two windings 1,000 times, or say from 100 volts to 100,000 volts, the turns ratio must be 1:1,000. In other words, there must be 1,000 turns in the secondary winding to every 1 turn in the primary winding. Thus, if the secondary should require thousands of turns of wire to obtain this ratio, it would make no difference, in so far as ratio is concerned, whether a No. 18 B. and S. or an exceptionally fine No. 40 B. and S. gage wire were used. The voltage induced depends upon the turns ratio and not the size of wire used.

If, on the other hand, it is desired to develop power in the secondary circuit, then it will be necessary to have both the proper turns ratio and the proper size of wire to accommodate the amount of current flow in the circuit. If the wire is too small for a given amount of current flow, an I^2R drop results in the winding which causes the output voltage to be reduced. Furthermore, if the current is increased much beyond the rated carrying capacity of the wire, the winding will burn out owing to the overload condition. Also, it must be remembered, that, even though the transformer may not burn out, the development of *too much* heat in the windings lowers the efficiency of the transformer.

d. Relation of Frequency to Transformer.—The current I_p drawn by the primary of a transformer varies indirectly as the impedance Z_p of the primary. Furthermore, the no-load impedance Z_p varies directly with the frequency f_p . Therefore, a given transformer designed, let us say, for 60-cycle operation has a primary impedance of 210 ohms when unloaded. At 105 volts this transformer will draw 0.5 amp. At 120 cycles the primary impedance is increased, let us say, to 420 ohms. The current drawn is then 0.25 amp., with no harm done to the primary winding.

Assume now that this transformer is connected to a 25-cycle line. The result is a lowered primary impedance, owing to the lower frequency, with a consequent rise in current. Let us say the primary impedance drops to 50 ohms. The current then rises to 2.0 amp. Under these conditions the primary winding would overheat and might possibly burn out unless it was designed for the overload.

It is obvious then that a transformer will not be harmed if it is used at a higher frequency than that for which it is designed, whereas it will be damaged if used on a lower frequency unless an overload tolerance is allowed for in the primary winding.

The frequency of the alternating current delivered by the secondary of a transformer is always the same as that impressed across the primary.

The transformer as used in rectifier units is discussed further in the chapter on Rectifier Units (Chap. 6).

II. INDUCTANCE

2.3. Induction.—When a current is first sent through a conductor, the lines of force around the conductor must be visualized as an expanding or moving magnetic field which expands until the apparent maximum

extended position has been reached. This all happens in a fraction of a second. If the current is suddenly turned off by opening the circuit, the magnetic field will contract or collapse and totally disappear. This expanding and contracting effect of the magnetic field is the basis of all electromagnetic induction between fixed circuits, and takes place only when the magnetic field is moving (expanding and contracting). Obviously the magnetic field moves only when the applied e.m.f. or the resistance of the circuit is varied, as in the case of interrupted direct-current or alternating-current circuits.

If a conductor is placed in the vicinity of another conductor carrying an e.m.f. of varying intensity, and consequently having a varying field, an e.m.f. will be induced in it because of its being cut by this varying magnetic field. The current in this conductor is called an induced current and is due to the phenomenon called *electromagnetic induction*. All induction due to the flow of a varying electric current is electromagnetic in character.

Let us imagine two coils *A* and *B*. A current of varying intensity is flowing through coil *A*. Coil *B*, if a closed circuit, being near coil *A*, has a current induced in it by induction. As the field in coil *A* dies down, the lines of force around coil *B* also die down. In so doing, they cut and induce an e.m.f. in coil *A*, so that a third e.m.f. is produced by induction. First, there is the original e.m.f. in coil *A*; second, the induced e.m.f. in coil *B*; and, third, a reinduced e.m.f. in *A* due to *B*. This phenomenon is called *mutual induction*.

2.4. Self-induction.—*a.* The lines of force around a coil, through which a varying current is flowing, will expand and contract as the current varies. As they rise and fall, the magnetic field around each turn of the solenoid cuts itself and many adjacent turns, and consequently produces an e.m.f. greater than for one turn, the amount of which is dependent upon the number of turns, the amount of current flowing through the turns, and the number of lines of force threading the coil. This action results in an induced e.m.f., which is in the direction opposite to the impressed e.m.f. of the coil, which tends to retard the flow. This opposing effect is present only when the field is varying. This phenomenon is called *self-induction*, because it is an e.m.f. induced in a conductor by its own moving magnetic field.

b. The *self-induction* of an electrical circuit is defined as *that phenomenon whereby an e.m.f. is induced in the circuit itself when the current in the circuit changes, or varies*. This important factor the student should understand thoroughly in order to comprehend clearly the function of inductances when they are connected in alternating-current circuits.

c. Referring again to Sec. 1.33 on Fields around Conductors, it was explained how a current passing through a wire creates a magnetic field about it, and how this field can be increased by coiling the wire into helical form and inserting into it an iron core. Let us consider what happens in the circuit itself when the magnetic field is either

expanding or contracting through a variation of the current flow; remembering that, whenever a current varies, the magnetic field around the wire correspondingly varies (moves). It is extremely important to grasp the following facts: *When a magnetic field fluctuates, it produces an e.m.f. in all conductors cut by it.* It is immaterial whether these conductors belong to a separate circuit, or whether they constitute the circuit (the helical coil referred to above) in which the magnetizing current is flowing.

d. The e.m.f. which causes the current to flow through the coil is called the *applied* e.m.f. There is also an e.m.f. which is produced by the circuit itself, independent of the applied e.m.f.; this is the *counter* e.m.f., and it is due to self-induction. For an example see Fig. 2-4. Here is a simple electric circuit, consisting of a battery, a switch, a resistance, and a coil. In this circuit a current is flowing continuously, whether the switch is open or closed; the difference being only in the strength of current, that is, when the switch is open, a minimum of current flows, owing to the resistance, and when the switch is closed, a maximum of current flows because the resistance is then short-circuited.

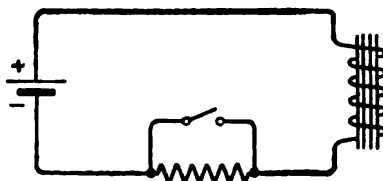


FIG. 2-4.—A simple electrical circuit to illustrate the effects of induction.

e. The student will readily see that in each of these situations there will be a magnetic field present about the coil. Hence, when the switch is open, the magnetic field of a certain density extends out from the coil. When the switch is closed, therefore, the field about the coil will increase in density. In other words, the field has actually expanded from a minimum to a maximum density when the switch is closed and from a maximum back again to a minimum when the switch is opened.

Now, it is quite apparent that if the switch should constantly be opened and closed, there would be a moving magnetic field, expanding and contracting at a definite rate, depending upon the speed with which the circuit is opened and closed. What effect would this action have on the circuit itself? This is one of the most important principles associated with all forms of electric circuits in which the current is changing or varying.

When a current is starting to flow in a conductor, due to an applied or impressed e.m.f., the magnetic field about the conductor is expanding and becoming denser. During this period of expansion, the field, consisting of magnetic lines of force, is cut through by the wire or coil by which it is produced. This causes a second current to be set up in this conductor, but in an opposite direction to that of the applied or impressed e.m.f. Therefore, during the period of field expansion, the coil or wire acts as an opposition to the applied e.m.f. and thus prevents the current in the circuit from reaching its maximum until the cutting of the field by the conductor has been completed. This continues usually for a fraction of a second only, but the significance of this result is readily seen when the circuit is made and broken at a great rate of speed.

Thus far, only the results of a starting or expanding field have been noted. When the circuit is broken and the current is decreasing, the process is reversed; the field as it contracts is again cut by the coil, but, as this cutting is now in the opposite direction, another self-induced e.m.f. is produced, which is now in the same direction as the impressed e.m.f. and which tends, therefore, to prolong the duration of current. The value of the back pressure at make (when the circuit is closed) is never greater than the impressed e.m.f., otherwise the current could not rise in value. Its value at break (when the circuit is opened), however, is not limited by any such condition, and, therefore, when the break is very sudden, its value at that instant may be very great.

f. Again, the magnetic field around a steady current represents a certain amount of energy stored up in the surrounding space. For example, it may be said that the energy was supplied at the expense of the current in the circuit when the e.m.f. was

started, and that this same energy was returned to the circuit when the current was stopped. The starting of a current in a circuit, therefore, resembles, in a logical manner, the starting of some heavy mass, a grinding wheel, for example. It cannot be started suddenly, nor does it naturally stop suddenly. Here the starting of the wheel would be analogous to a force overcoming the inertia of the mass; in electrical terms the highly inductive circuit is analogous to a body of great mass. Referring again to the wheel, the amount of energy associated with it when in steady motion, and the magnitude of all the effects depending on that energy, will vary with its mass. This example illustrates the effect produced by induction in a circuit, and any conductor or coil producing these effects by virtue of its inductive properties is called an inductance. *Self-induction* in a circuit, therefore, tends to prevent a change in the strength of the current flowing through it. This is sometimes called the *flywheel effect*.

g. Hence it can readily be seen that the greater the number of turns in a coil, or, even more so, the greater the amount of iron in the core of a coil, the greater will be its *self-inductance*, and therefore, the greater the self-inductance of any circuit, the greater will be its ability to oppose the e.m.f. impressed upon it. From this it can clearly be understood that there might be a possibility of a circuit having a self-inductance so large that very little current of a varying character could pass through it.

h. Lenz's Law.—The summarizing of Lenz's law as applied to *self-induction* may, therefore, be defined as that phenomenon in which an e.m.f. is induced in the circuit itself during the period in which the electrons in the circuit are accelerated or coming to a stop. This e.m.f. is called the counter e.m.f. caused by self-induction, and it always produces a magnetic field which opposes any change in the force which produces it. Counter e.m.f. is always present in a circuit when the current in the

circuit is changing or varying and is proportional to the rate at which the current is varying.

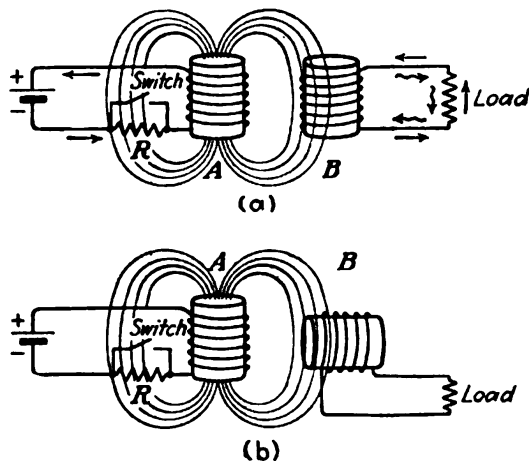


FIG. 2-5.—Two coils in axial relation to show effect of mutual induction.

2.5. Mutual Induction.—*a.* Figure 2-5(a) illustrates two coils *A* and *B* placed in an axial relationship to one another. Coil *A* is arranged with a switch and resistance *R* for varying the rate of current flow without actually opening the circuit. Assuming a steady flow of current through coil *A* with the short-circuiting switch open, coil *B* is brought into close rela-

relationship with the steady magnetic-field condition surrounding it, because of the non-varying amplitude of the current flow. The free electrons in coil *B*, although in a state of constant agitation due to temperature, are not moving progressively from point to point and consequently do not constitute a flow of electric current.

b. If now the switch is closed, short-circuiting the resistance *R*, the flow of the electrons through the coil *A* will be increased, causing a sudden accelerating action

of the electrons in the circuit. This will result in a momentary expansion of the magnetic field about coil *A* and a pulse movement in the space surrounding the coil. Now, since coil *B* is assumed to be located within this area, the free electrons within this coil will be subjected to the moving magnetic forces about the coils and will be displaced in a definite direction as indicated by the wavy arrows. In other words, the current flow in the coil *B* (the induced current) will be in an opposite direction to that in the coil *A* during the period in which the current in the coil *A* is increasing. The straight arrows indicate the direction of the induced current during the period in which the current in coil *A* is decreasing.

c. As soon as the field has expanded and ceases to move, the electrons in the circuit of coil *B* will cease to move progressively and the current flow will stop. If now the switch is opened, the number of free electrons moving progressively in circuit *A* will be decreased, resulting in the contraction of the magnetic field. The electrons in circuit *B*, however, are again subjected to a movement of the magnetic field and are urged to move in an opposite direction to that in which they were displaced when the field was expanding. Hence, if the switch in circuit *A* is repeatedly closed and opened, an alternating e.m.f., and an alternating current, will be induced in circuit *B*.

d. The direction of the induced current in circuit *B* will be opposite to that of the current flow in circuit *A*, owing to the mass effect of the electrons in the circuit during the period in which they are being set in motion. Hence, the current flow in the circuit *B* will be in the same direction as that in circuit *A*, only during the period in which the current flow in circuit *A* is decreasing. *Current flow is present in circuit B only during the period in which it is cutting or being cut by moving magnetic lines of force.* The term *cut* or *cutting* refers to the action of the magnetic lines of force upon the free electrons in the conductor and depends upon the *movement* of the field or coil and the position of the coil with respect to the lines of force.

e. Figure 2-5(b) illustrates a position of two coils *A* and *B* in which no e.m.f., and consequently no current, is induced into circuit *B*, even though the magnetic field about the coil *A* is assumed to be moving. This is due to the fact that the lines of force are parallel with the turns in the conductor, and therefore they do not displace any electrons in the circuit *B*. For further information on this action see explanation of Fig. 7-30.

f. Let us assume the coil *B* to be in the proper magnetic relation to coil *A*, and the field about coil *A* to be expanding and contracting due to a varying e.m.f., such as is produced by opening and closing the switch in rapid succession. An alternating current will flow in the circuit *B* because of the constant displacement of electrons in that circuit. This will result in the creation of a magnetic field around coil *B* because of the continuous movement of electrons in the circuit.

g. However, since these electrons are first displaced in one direction and then in the other, the polarity of the magnetic field around the coil *B* will be constantly changing, the number of changes depending upon the rate of interruption in the inducing circuit *A*.

h. The magnetic field now present about the coil *B* will have an effect upon the moving electrons in the circuit *A* and, consequently, its magnetic field. This results in a constant action and reaction of both magnetic fields upon one another during the period in which the current in any one circuit is changing or varying. It is this effect of the magnetic reactions between circuits which is called *mutual induction*, and all circuits which are so related are referred to as magnetically coupled circuits.

i. The effect of induction is a measurable property of a circuit and is called *inductance*. The physical unit (coil or conductor) in the circuit causing this effect is called or referred to as an *inductance*. The term inductance may, therefore, mean an abstract property of a circuit or a component part of the circuit.

j. The effects of magnetic coupling reactions between circuits are treated more thoroughly under Transformers (Sec. 2.2) and Analysis of Tuned Circuits (Sec. 5.19).

2.6. Inductance Measurements.—The ability of a coil to function as a storehouse of electrical energy in magnetic form is expressed in electromagnetic units measured in centimeters which for practical purposes are called *henrys*, in honor of the discoverer of electromagnetic induction, Joseph Henry (1797–1878). Self-inductance is denoted by the letter L and is an expression of electrical mass or ability to store up energy in electromagnetic form.

This is dependent upon the number of turns in a coil, the diameter of the coil, the length of the coil, the character of the core, and the varying current flow in the coil. Hence the self-inductance of a coil can be calculated by the general expression

$$L = \frac{N\phi}{I} \quad (10)$$

where L = the coefficient of self-inductance.

N = the number of turns in the coil.

ϕ (phi) = the total number of lines of force linkages with one turn.

I = the varying current flow in the coil.

Inasmuch as a henry is the inductive effect produced when 10^8 lines of force are cut when 1 amp. is turned on or off in a circuit, this formula may be rewritten as

$$L = \frac{N\phi}{10^8 I} \text{ henrys} \quad (10a)$$

A coil is said to have a value of 1 henry of inductance if a varying current of 1 amp. per second induces an e.m.f. of 1 volt in the circuit. Similarly, if two circuits are magnetically coupled, the mutual inductance will be 1 henry if a varying current of 1 amp. per second induces an e.m.f. of 1 volt into the second circuit. Thus, since the self-inductance of the coil is proportional to the square of the number of turns, the mutual inductance of two inductances will, therefore, vary as the square root of the two inductances, or

$$M = \sqrt{L_1 \times L_2} \times k \quad (11)$$

[For value of k see Eq. (20).] Also the induced voltage may be computed by the ratio

$$E = M \frac{I}{t} \quad (12)$$

where t = time in seconds.

However, since the electrons in the secondary circuit accelerate in an opposite direction to those in the primary circuit, the induced e.m.f. and current will be out of phase. Hence to indicate this condition in the formula a — (minus) sign should be inserted, thus

$$E = -M \frac{I}{t}$$

In other words, this serves to indicate that the e.m.f. in the secondary circuit is in a direction which tends to oppose that which is producing it. Similarly, if the counter e.m.f. caused by self-induction in a single circuit is to be determined, simply change the symbol from M to L , thus

$$E = -L \frac{I}{t} \quad (13)$$

These formulas are theoretical and do not apply to practical designing where other variable factors affect the results.

2.7. Practical Inductance Formulas.—The self- or mutual inductance of a wire or coils may be calculated from their respective geometrical dimensions by many formulas. Some of the more important ones directly applicable to practical design will follow. All calculations are expressed in centimeters, since it will be a simple matter to convert these values into inches and henrys as follows:

1 centimeter = 0.3937 inch, or 0.01 meter (1 in. = 2.54 cm.).

1 henry (h.) = 1,000,000,000 centimeters, or 10^9 cm.

1 millihenry (mh.) = 1,000,000 centimeters, or 10^6 cm.

1 microhenry (μ h) = 1,000 centimeters, or 10^3 cm.

1 centimeter of inductance = 0.000000001 henry.

1 henry = 1,000 mh. = 1,000,000 μ h.

To convert centimeters into microhenrys, divide by 1,000 or multiply by 10^{-3} .

1. *For Parallel Wires.*—For a circuit in which the current flows in two parallel wires, the magnetic fields react in a manner in which both fields may subtract or add.

$$L_{eff} = L_1 + L_2 \pm 2M \quad (14)$$

where L_1 and L_2 = the self-inductance in centimeters of the two wires, and M = the mutual inductance in centimeters between them.

2a. *For a Single-layer Coil (Air Core).*

$$L = 4\pi^2 r^2 n^2 l K \text{ cm. (Nagaoka's formula)} \quad (15)$$

where r and l (radius and length) are expressed in centimeters.

n = number of turns per centimeter.

K = constant factor determined by the ratio of d/l (see Table IIA).

If the total number of turns of wire are used, instead of the number of turns per centimeter, the formula may be expressed

$$L = \frac{4\pi^2 r^2 N K}{l} \text{ centimeters} \quad (16)$$

(cm. $\times$ 0.001 = μ h)

where N = the total number of turns.

This formula is based upon the assumption that the spacing between the turns is infinitely small, that is to say, the turns may actually touch without making electrical contact. If, however, insulation or space-wound coils are required, then a correction factor must be used in order to obtain accurate results.

To make the necessary correction for this condition, subtract the quantity Δ from the result of the previous formula.

$$\Delta = 2\pi dn[A + B] \quad (17)$$

where n = number of turns per centimeter.

A = ratio of d_0/D_1 .

d_0 = diameter of the bare wire.

D_1 = diameter over the insulation or the distance between the centers of consecutive turns.

B = the total number of turns on the coil.

d = the diameter of the coil in inches.

l = the length of the winding in inches.

b. For rapid and fairly accurate calculation of the inductance of a single-layer air-core coil, the following formula may be used:

$$L = \frac{0.067 \times d^2 \times N^2}{d + 3l} \quad \text{microhenrys} \quad (18)$$

TABLE IIA.—VALUE OF K FOR NAGAOKA'S FORMULA ($L = 4\pi^2 r^2 n^2 l K$ cm.)
(For helical-wound coils)

Ratio of d/l	K	Ratio of d/l	K	Ratio of d/l	K
0.05	0.9791	1.9	0.5379	5.6	0.2981
0.1	0.9588	2.0	0.5255	5.8	0.2916
0.2	0.9201	2.2	0.5025	6.0	0.2854
0.3	0.8838	2.4	0.4816	6.2	0.2795
0.4	0.8499	2.6	0.4626	6.4	0.2739
0.5	0.8181	2.8	0.4452	6.6	0.2685
0.6	0.7885	3.0	0.4292	6.8	0.2633
0.7	0.7609	3.2	0.4145	7.0	0.2584
0.8	0.7351	3.4	0.4008	7.2	0.2537
0.9	0.7110	3.6	0.3882	7.4	0.2491
1.0	0.6884	3.8	0.3764	7.6	0.2448
1.1	0.6673	4.0	0.3654	7.8	0.2406
1.2	0.6475	4.2	0.3551	8.0	0.2366
1.3	0.6290	4.4	0.3455	8.5	0.2272
1.4	0.6115	4.6	0.3364	9.0	0.2185
1.5	0.5950	4.8	0.3279	10.0	0.2033
1.6	0.5795	5.0	0.3198	11.0	0.1903
1.7	0.5649	5.2	0.3122	12.0	0.1790
1.8	0.5511	5.4	0.3050	13.0	0.1692

Example 1: Find the inductance of a single-layer coil of 10 turns wound on a cylinder of 1.5 in. in diameter, the length of the coil being 0.61 in. Proceed as follows:

$$L = \frac{0.067 \times 1.5^2 \times 10^2}{1.5 + 3 \times 0.61} = 4.52 \mu\text{h}$$

Comparing this result with the extremely accurate Nagaoka formula, we find

$$L = 4.4 \mu\text{h} \text{ (Nagaoka)}$$

compared with

$$L = 4.52 \mu\text{h}$$

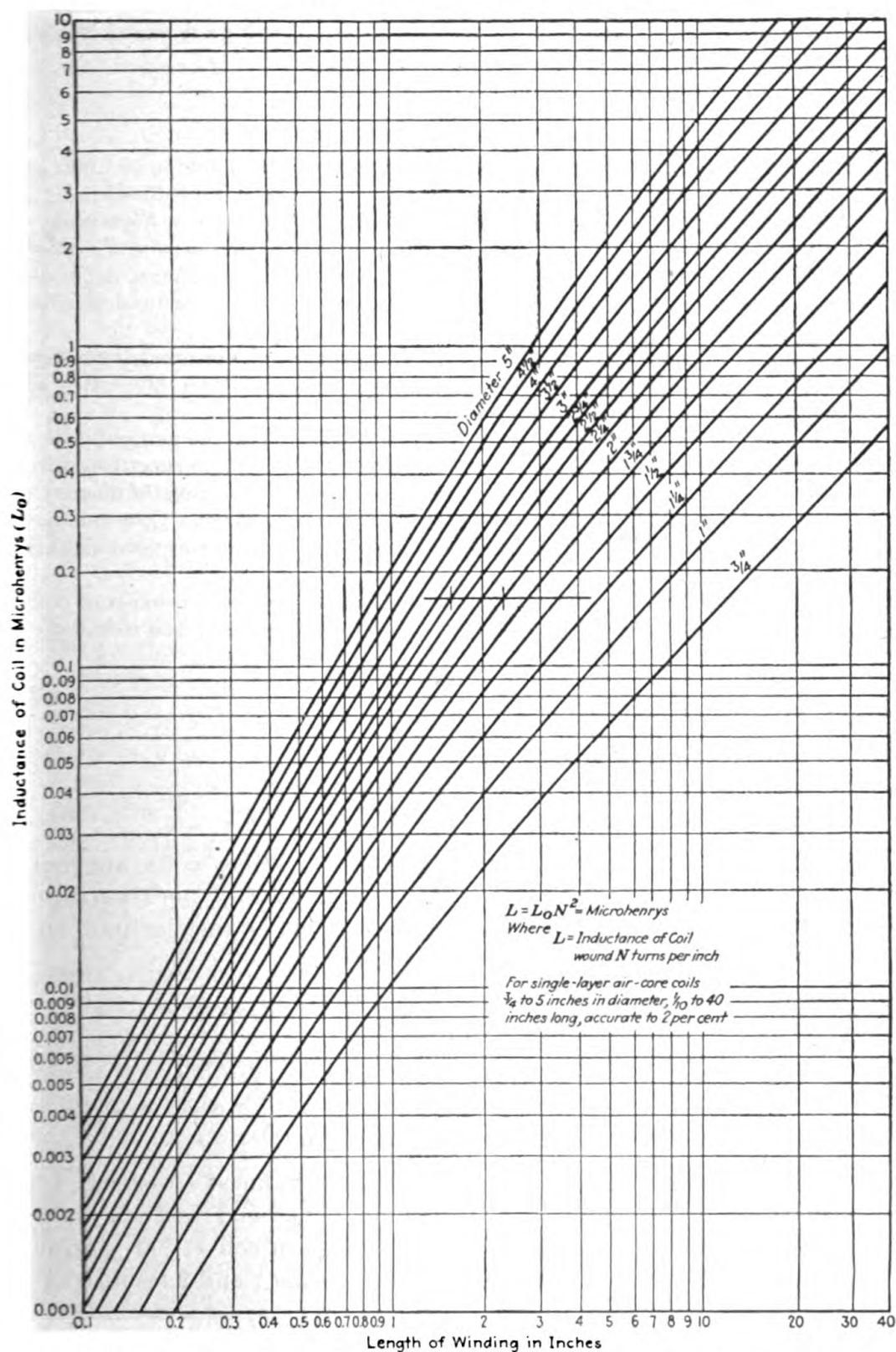


FIG. 2-6.—Curves based on Nagaoka's inductance formula. (Courtesy of Electronics.)

Example 2: To find the inductance of a single-layer coil having a diameter of 4 in., 100 turns, and a length of 2.2 in.,

$$L = \frac{0.067 \times 4^2 \times 100^2}{4 + 3 \times 2.2} = 1,010 \mu\text{h}$$

The same coil calculated from the Nagaoka formula (15) was found to be 1,000 μh .

A set of curves based on Nagaoka's inductance formula is reproduced here as Fig. 2-6, by permission of the publishers, from the April, 1931, issue of *Electronics*.

3. For Iron-core Coils (Closed Core).—The previous calculations have been entirely for single-layer coils without magnetic cores, in which case the inductance depended principally upon the geometrical dimensions, with a small correction factor depending upon the frequency through the coil.

For iron-core coils, however, the inductance L depends on the physical dimensions of the coil and the physical properties of the iron, and, since these properties are variable, the calculations will be more difficult.

The inductance of an iron-core coil, therefore, depends upon the permeability of iron, and this will vary over the cross section of the core since the magnetizing force is not constant over that area. Also, if the current in the coil producing the magnetizing force varies, the value of the magnetic permeability μ will change. Consequently, some average value of the permeability must be obtained in order to make definite computations.

Perhaps one of the most simple formulas that can be derived for iron-core coils, if we assume the most general conditions, namely, that of a closed iron core with a small air gap, is

$$L = \frac{0.4N^2\mu A}{l} \quad (19)$$

where L = inductance in henrys.

l = length of the air gap in centimeters.

A = area of the surface of the iron core at the air gap.

$\mu = 1$.

2.8. Mutual Inductance Measurements.—*a.* When coils are connected in series so that their respective magnetic fields do not react upon one another, the effective or total inductance would be the algebraic sum of the separate inductances, expressed as follows:

$$L = L_1 + L_2$$

b. If the coils are placed close enough to cause magnetic reaction between them, then

$$L = L_1 + L_2 \pm M_{1,2} \pm M_{2,1}$$

where $M_{1,2}$ is the mutual inductance or the e.m.f. induced across coil 1 by the rate of the current change in coil 2 (1 amp. per second) and $M_{2,1}$ is the e.m.f. induced into coil 2 by the current change in coil 1. $M_{1,2}$ equals $M_{2,1}$. Hence, the e.m.f. reactions between the coils 1 and 2 result in

$$L = L_1 + L_2 \pm 2M$$

Now, if the coils are so connected that the magnetic fields assist each other, then

$$L_a = L_1 + L_2 + 2M$$

Consequently, if the windings of one coil are changed, so that the current flows in a different direction in one coil than in the other coil, the magnetic fields oppose and react as follows:

$$L_o = L_1 + L_2 - 2M$$

Hence,

$$L_a - L_o = 4M$$

and thus

$$M = \frac{L_a - L_o}{4}$$

c. The degree of magnetic coupling reactions, or the coupling coefficient k , as it is generally called, may thus readily be computed by the ratio

$$k = \frac{M}{\sqrt{L_1 \times L_2}} = \frac{L_a - L_o}{4\sqrt{L_1 \times L_2}} \quad (20)$$

where M represents the mutual inductance in henrys.

$$M = \sqrt{L_1 \times L_2} \times k \quad (11)$$

The value of the coupling coefficient k will lie somewhere between 0.5 and zero if the coils are widely separated (loosely coupled), and between 0.5 and one if closely related (tightly coupled).

III. CAPACITY

2.9. The Electrostatic Field and the Condenser.—When two metal plates are separated by air or some other insulating material, an electric field will be present between them when the two plates are connected to a source of constant e.m.f. It is supposed that electric lines of force extend between the positive and negative plates in the form of an electrostatic strain or force, representing stored electrical energy.

This hypothesis may be substantiated from the evidence that a meter connected in series with the two plates will show a progressive movement of electrons (current flow) through the entire circuit at the instant the circuit is closed which immediately thereafter decreases gradually back to zero. Now, although the circuit is still closed, there is no longer any indication of current flow, and yet, if the applied e.m.f. to the plates is disconnected and a pressure-indicating meter (voltmeter) connected across the plates, a discharge deflection will be noted. This definitely indicates that the area between the plates had been strained and a difference of potential established, which, when connected to the voltmeter,

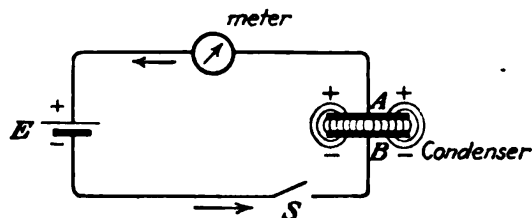


FIG. 2-7.—Simple circuit to show charging of a condenser.

was relieved in moving the circuit electrons through the voltmeter coil and its resistance. The action is illustrated in Fig. 2-7.

It can readily be seen that the charging of a condenser is the process of raising the potential of one plate to a higher point with respect to the other; or, in other words, the condenser is said to be charged. This condition is generally represented by vertical lines between the plates as indicated in Fig. 2-7 to show that a state of strain exists between the plates when an e.m.f. is applied. If the charged condenser is disconnected from the charging e.m.f. and shunted by a high-resistance conductor, the potential difference will cause the electrons in the shunt circuit to be moved in the direction of the positively charged plate, thus neutralizing the potential difference. When this takes place the condenser is said to be discharged.

2.10. Capacity of a Condenser.—The number of electrons necessary to establish a difference of potential between two plates is a measure of the *capacity* of the condenser thus formed.

The unit of electrostatic capacity is called the *farad*. A condenser which has a capacity of 1 farad would require 1 coulomb of electricity to bring its plates up to a potential difference of 1 volt. However, since the physical dimensions of a condenser with that capacity would involve a tremendous plate area, it is not used for practical purposes. In electrical- and radio-engineering practice the values of capacity are generally always expressed in micro-units, or microfarads. The microfarad is 1/1,000,000 part of 1 farad, consequently a condenser having a capacity of 1 mf. would require a charge of 1/1,000,000 of 1 coulomb to charge it up to a potential difference of 1 volt. Stated in another way, a current of 1 μ a. flowing for 1 sec. would charge the plates to a potential difference of 1 volt.

The capacity of any condenser is measured by the quantity of electricity with which it must be charged in order to raise its potential from zero to unity. In other words, a small capacity would require only a small quantity of electricity to raise its potential from zero to unity while, on the other hand, a large capacity requires a greater quantity of electricity to establish a potential increase from zero to unity. Thus it can be clearly seen that the potential of a condenser depends upon the quantity of charge and its capacity:

$$C = \frac{Q}{E} \quad (21)$$

or

$$Q = CE \quad (22)$$

The capacity of a condenser is increased by one or more of the following methods:

- a. Increasing the area of the metal plates.
- b. Decreasing the distance between the plates (thinner dielectrics).
- c. Increasing the dielectric constant of the insulating material.

2.11. Specific Inductive Capacity.—The specific inductive capacity, or the dielectric constant, of various insulating materials is the ability of such materials to have electric lines of force produced in them compared to the lines that would be produced in air.

Let us assume a condenser made up of two plates separated by an air spacing of $\frac{1}{32}$ in., and let the quantity of electricity required to charge it to 1 volt be measured. Then let $\frac{1}{32}$ -in. mica or glass plate be inserted in place of the air dielectric and the quantity of electricity again measured. It will now be found that the quantity of electricity is somewhere between five and ten times as much as when the air dielectric separated the plates.

It is this ratio of the capacity of a condenser when other than air is used, to that if air is used, which is called the *specific inductive capacity* of a dielectric.

The following table gives some values of specific inductive capacities of various insulating dielectrics relative to air.

TABLE IIB.—SPECIFIC INDUCTIVE CAPACITIES

Substance	Dielectric Constant <i>K</i>
A vacuum.....	0.94
Hydrogen.....	0.9997
Air at 0°C.....	1.000586
at 20°C.....	1.000576
Carbon dioxide.....	1.0008
Gases.....	1.00007–1.009
Liquid oxygen.....	1.478
Oil.....	2.2–4.7
Paraffin wax.....	1.99–2.29
Sulphur.....	2.24–4.2
Ebonite.....	2.6–3.48
Rubber.....	2.0–3.5
Paper, dry.....	2.0–2.5
Fiber.....	2.5–5.
Shellac.....	2.74–3.73
Gutta-percha.....	3.3–4.9
Quartz.....	4.49–4.55
Bakelite.....	4.5–5.5
Glass, various grades.....	5.0–10.0
Mica.....	2.5–6.7
Porcelain.....	5.7–6.8
Slate.....	6.6–7.4
Water.....	81.0

Water has an exceptionally high dielectric constant but cannot be used because of its electrical conductivity due to ionization.

2.12. Energy in a Charged Condenser.—The amount of energy or work done in establishing an electric field between the plates of the condenser so as to establish a difference of potential is expressed in joules. This represents an expenditure of energy which may be readily calculated from the formula

$$W = \frac{1}{2}CE^2 \quad \text{joules} \quad (23)$$

Thus, when a condenser is charged, the potential energy is supplied by the source e.m.f., and, when it is discharged, its potential energy is converted into kinetic energy (the motional energy representing the electrons in motion).

2.13. Capacity of Condensers in Parallel.—Figure 2-8 represents a common arrangement of condensers in parallel.

Assuming each condenser to have an individual capacity of 0.002 mf., the total effective capacity will be 0.006 mf. This can readily be seen to be so owing to the larger combined electrode area of the condensers. Let the letter Q represent the total charge given to them; then a difference of potential of E units between the points X and Y , which are the terminals of the systems, is produced.

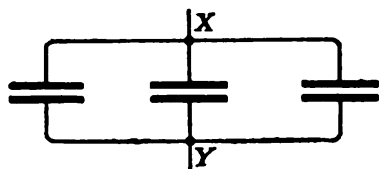


FIG. 2-8.—Three condensers in parallel.

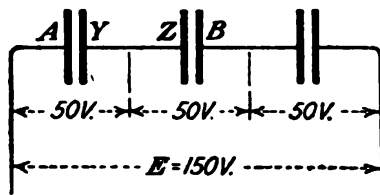


FIG. 2-9.—Three condensers in series.

The charges in the condensers will be greater, therefore, owing to the increase of plate area, but the E will be the same for all of them.

Thus, if the charges q of each condenser are added,

$$Q = q_1 + q_2 + q_3 \quad (24)$$

Hence, if the total capacity of three condensers connected in parallel is the result of the addition of the three charges, the formula for condensers in parallel will obviously be

$$C = C_1 + C_2 + C_3 \quad (25)$$

2.14. Capacity of Condensers in Series.—Figure 2-9 represents three condensers connected in series. Assuming each condenser to have a capacity of 0.002 mf., the total effective capacity under this arrangement will be less than the lowest of the component capacities. That this is so follows from the reasoning that q on each condenser of a series bank of condensers must be the same since the negative charge on plate Y equals

the positive charge on plate Z, and so on. Then as

$$E = \frac{Q}{C}, \quad E_1 = \frac{Q}{C_1}, \quad E_2 = \frac{Q}{C_2}, \quad E_3 = \frac{Q}{C_3}, \text{ and so on,}$$

and $E = E_1 + E_2 + E_3$, and so on.

$$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}, \text{ and so on.}$$

Dividing out Q we get

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}, \text{ and so on.}$$

This equation when transposed becomes Eq. (27) below.

The formula for condensers of equal capacities connected in series is expressed as follows:

$$C = \frac{c}{n} \quad (26)$$

where n represents the number of condensers and c the capacity of one condenser.

Hence, in the above example,

$$C = 0.0006\frac{2}{3} \text{ mf.}$$

If the condensers are of unequal capacities, however, the formula reads as follows:

$$C = \frac{1}{\frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_3}} \quad (27)$$

Example: Three condensers having capacities of 0.002, 0.004, 0.002 mf. are connected in series. What is the total effective capacity?

Solution:

$$C = \frac{1}{\frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_3}}$$

or

$$C = \frac{1}{\frac{1}{0.002} + \frac{1}{0.004} + \frac{1}{0.002}} = 0.0008$$

Answer: Total effective capacity = 0.0008 mf.

It will be seen that whenever unequal capacities are connected in series, the total effective capacity will always be less than the smallest condenser value in the circuit.

Why the capacity is reduced when condensers are connected in series will be understood by analyzing the dielectric effect in the two condensers of Fig. 2-9.

The plates Y and Z, being electrically connected, actually form a single plate. Assuming the dielectrics of each capacity to have a like thickness, it can readily be seen that by joining both dielectrics in a series formation, the distance between plates

A and B is merely widened and, consequently, the thickness of the dielectric is increased. If each of two condensers has a capacity of 0.002 mf., therefore, and is connected in series, the dielectric thickness is doubled and results in a reduction of capacity to one-half of its former value, or 0.001 mf.

From this it can be seen that the capacity of n number of equal condensers connected in parallel and charged from the same source would represent a total energy of

$$W = \frac{1}{2} E^2 \times n \times C \quad \text{joules} \quad (28)$$

Evidently, each constituent condenser is charged to the same extent as a single condenser, and the combination has, therefore, n times more energy, or, in other words, the parallel combination is equivalent to one condenser of n times greater capacity.

If a number of condensers, n , are connected in series, the capacity is C/n , and, consequently, the total energy is

$$W = \frac{1}{2} E^2 \frac{C}{n} \quad \text{joules} \quad (29)$$

Now, as the total energy is equally shared by the constituent condensers, each must possess $1/n^2$ of the amount that each single condenser must have. Also, if we consider that the potential difference between the plates of each condenser is E/n , then the individual energy stored between the plates of each condenser is

$$W = \frac{1}{2} \left(\frac{E}{n} \right)^2 \times C \quad \text{joules} \quad (30)$$

2.15. Capacity Measurements.—It has been shown that the capacity of a conductor or condenser is defined and measured by the quantity of electricity required to raise its potential from zero to unity. The capacity given by this expression is the capacity with reference to the body or bodies at zero potential from which the potential of the given conductor or condenser is raised by the charge.

The general formula for determining the approximate capacity of a condenser consisting of two parallel plates separated by any form of dielectric may be expressed as follows:

$$C = \frac{KA}{4\pi d} \quad \text{electrostatic units or centimeters} \quad (31)$$

where A = area of one metal plate in square centimeters.
 d = distance between the plates (thickness of the dielectric) in centimeters.
 K = the dielectric constant (see Table IIB, preceding).
 C = the capacity in centimeters.

$9 \times 10^5 \text{ cm.} = 1 \text{ mf.}$

If the condenser consists of more than two separate plates, the formula becomes

$$C = \frac{nKA}{4\pi d} \quad \text{centimeters} \quad (32)$$

where n = the number of dielectric sheets between the plates.

These formulas cannot give very accurate results, regardless of the care exercised in making the physical measurements, because of the curvature of the electrostatic field between the outside edges of the plates. For practical purposes, however, the calculations become sufficiently accurate for approximate determinations of capacity.

For the calculations of approximate capacity in variable semicircular plate condensers the formula is relatively more complicated:

$$C = Kn \frac{\pi(r_1^2 - r_0^2)}{4\pi d} \times \frac{\theta}{360} \quad (33)$$

where r_1 = the radius of the smaller sets of plates, r_0 the radius of the fixed plates, n the number of dielectric sheets between the plates, and θ the angle in degrees through which the rotary plates have been turned from the position of minimum capacity.

The formula may be greatly simplified by assuming the use of an air dielectric variable condenser with the entire number of rotary plates meshed in a position of maximum capacity. Then the total capacity may be calculated from the formula

$$C = \frac{2nA}{4\pi d} \quad \text{centimeters} \quad (34)$$

where n = the total number of rotary plates.

d = the thickness of the dielectric between one stator and one rotary plate in centimeters.

A = the area of one rotary plate in centimeters.

Example: A variable condenser has three rotary plates and four stationary plates. The rotary plates are each of a 6 sq. in. area and are semicircular in shape. The dielectric sheet is of air with a thickness of 0.03 in. Find the capacity of the condenser when the plates are closed or in a maximum capacity position.

Solution:

Using formula (34), first convert inches into centimeters.

$$\pi = 3.1416$$

$$1 \text{ cm.} = 0.04 \text{ in. (approx.)}$$

$$1 \text{ in.} = 2.54 \text{ cm.}$$

Hence,

$$C = \frac{2nA}{4\pi d} = \frac{2 \times 3 \times 38.71}{4 \times 3.1416 \times .0762} = 242 \text{ cm.}$$

To convert centimeters into micromicrofarads, multiply by 1.1124 (1 cm. = 1.1124 mmf.).

Answer: 242 cm., or approximately 0.00027 mf., or 270 mmf.

These are all methods of calculating capacity where no measuring instruments are required, only an accurate physical calculation of the geometric structure being necessary. They are given here principally to show what factors affect the capacity of a condenser.

IV. ELEMENTS OF ALTERNATING-CURRENT ENGINEERING

2.16. Construction of a Sine Wave.—A theoretical operating knowledge of all alternating-current circuits of either a low or high frequency depends primarily upon a fundamental understanding of trigonometry. It is important, therefore, that the reader study trigonometric principles to obtain a thorough working knowledge of alternating-current power and radio circuits.

It has been shown that an alternating current, also designated a.c., is a current which changes its direction or flow periodically, starting from zero voltage in one direction, rising to maximum and falling to zero and repeating in the opposite direction. This condition may be clearly seen by referring to Fig. 2-10 in which the alternating e.m.f. is indicated

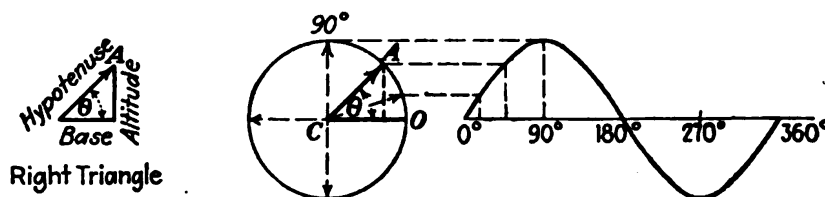


FIG. 2-10.—A vector or clock diagram of one cycle of alternating current.

by the curve and its phase position at any instant by the moving arm *A*. This arm is pictured to move in a counterclockwise direction through 360 degrees of a circle which represents one complete cycle of alternating e.m.f. or current. The arm which moves about the circle is called a *vector* or *clock diagram* and represents a definite angular relationship to its horizontal axis, or its vertical component. The angle between the horizontal radius *CO* and the vector *CA* (described by the counterclockwise rotation of the vector) is called the *phase angle* and is expressed by the Greek letter θ (theta). It may be clearly seen that the movement of the vector through 360 degrees of a cycle may serve to indicate the exact relationship of voltage or current with respect to one another or the horizontal axis. There are two types of vectors which may occur in alternating-current problems, namely, *space* and *rotating* vectors.

Space vectors are those in which there is a fixed direction in space, and rotating vectors are those in which there is a constant magnitude and angular velocity. The latter vectors are also known as *time* vectors.

Alternating currents or e.m.fs. which vary sinusoidally with time are generally expressed by rotating vectors but in such a manner that the rotating vector of fixed magnitude revolves with a constant angular velocity. If the length of the vector represents the maximum value of e.m.f. of current, as the case may be, its projection on a fixed reference

axis is the value of the voltage or current at the instant of time considered. That is to say, the number of revolutions per second made by the revolving line is equal to the number of cycles gone through by the voltage or current per second.

Rotating vectors may thus be handled by any of the procedures used in space vectors by merely considering them at some particular instant of time, or they may be treated by methods which are applicable to them alone.

All vectors may be readily analyzed by the application of fundamental trigonometric formulas as applied to the solution of triangles. A knowledge of the solution of the right triangle is absolutely essential since it may be clearly seen that the position of the vector arm with relation to the horizontal axis is always a definite angular expression. Voltage and current relationships may thus be readily comprehended if the various angular functions of trigonometry are clearly understood.

If the instantaneous values of the voltage or current follow one another according to a sine law, such as in the case of the single-phase alternating-current wave shape illustrated in Fig. 2-10, then the instantaneous voltage or current may be determined by the expression

$$i \text{ or } e = I_{\max} \text{ or } E_{\max} \times \sin \omega t \quad (35)$$

where $E_{\max}$ and $I_{\max}$ = maximum value of the wave or its amplitude

i and e = instantaneous values

ωt = radians per second

The abscissa for one cycle is taken as 360 degrees or 2π radians and corresponds to one complete revolution of an armature in a simple 2-pole alternator. In other words, 2π radians correspond to one complete cycle of alternating e.m.f. or current. A simple sine wave in relation to the time factor is shown in Fig. 2-11.

All waves which follow this sine law are called *sinusoidal* or simple-harmonic motions and may serve to express either simple-harmonic voltage or current waves.

Referring to the sine wave in Fig. 2-10, we find that the voltage or current at any instant may then be readily determined by multiplying the maximum or peak value of the e.m.f. or current by the sine of the angle at that instant.

Thus,

$$e = E \sin \theta$$

$$i = I \sin \theta$$

where e or i = the instantaneous voltage or current value, and θ = the phase angle ωt .

For example, if the peak e.m.f. is assumed to be 120 volts, it will be found that the instantaneous e.m.f. at some part of the cycle, say at 30 degrees, will be $E = \sin \theta$, or $e = 120 \times 0.5$, or 60 volts.

2.17. Frequency and E.M.F. Formulas.—As has been explained before, a cycle of alternating current is a complete reversal of the current,

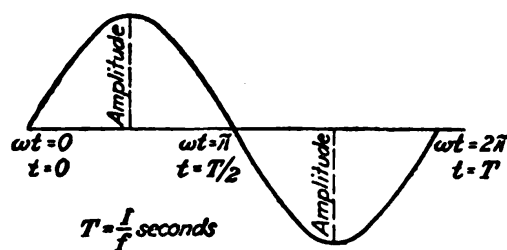


FIG. 2-11.—Simple sine wave for one cycle.

each cycle consisting of two alternations. The number of cycles taking place per second is referred to as the *frequency* of that particular current.

For example, in an alternator having a frequency of 500 cycles per second there are 1,000 alternations a second. It is preferable to specify the frequency of an alternator, in cycles per second, as for example, a 60-cycle alternator, a 120-cycle alternator, a 500-cycle alternator, and so on.

The following formula shows how the frequency of an alternator may be determined.

$$f = \frac{N}{2} \times \frac{\text{r.p.m.}}{60} \text{ c.p.s.} \quad (36)$$

where N = number of field poles.

r.p.m. = speed of the armature in revolutions per minute.

Example: A certain alternator has 24 field poles and runs at 3,500 r.p.m. What is its frequency?

$$f = \frac{24}{2} \times \frac{3,500}{60} = 700 \text{ c.p.s.}$$

Example: An alternator is run at 600 r.p.m. and is to give a frequency of 60 cycles. What number of poles is required?

$$N = \frac{2f60}{\text{r.p.m.}} \quad (37)$$

Hence

$$N = \frac{2 \times 60 \times 60}{600} = 12 \text{ poles}$$

It is to be noted that the frequency formula (36) applies only to the revolving-field or revolving-armature types of alternators. It is evident that it could not be applied to an inductor-type alternator. The frequency of an inductor-type alternator is equivalent to the number of inductors which pass a given point per second. For example, the alternator in Fig. 17-3 has a rotor with 12 teeth. Therefore, to generate a 500-cycle alternating current, it would be necessary that the rotor revolve 41.6 times ($500 \div 12$) per second, or approximately 2,500 r.p.m.

Probably the most useful equation used in electrical engineering is the e.m.f. formula. This formula is derived by a consideration of numerous factors. To generate 1 volt it has been determined that it is necessary for a conductor to pass 10^8 lines of force per second. Therefore, the flux density of the field must be represented. The number of conductors connected in series to form the armature must also be considered. Also the number of times each conductor passes a field pole, or, the speed of cutting must be included. In addition, as the flux is dependent upon the area of the pole faces, this area must be considered. All of these factors must be multiplied by a constant K which will depend on certain variable factors, such as arrangement of windings and other design rela-

tions known to the designing engineer. The equation may then be stated as

$$E = \phi \times N \times f \times K \quad (38)$$

The constant K combines several figures which become apparent when they are separately analyzed. We know that for every complete revolution the armature conductor passes 2 poles; therefore, $2f$ poles pass a conductor per second. As the conductor must pass 10^8 lines of force (maxwells) per second to generate 1 volt, the average volts per conductor will be $2f \times \phi \div 10^8$. Now, as each armature turn consists of two conductors in series, the volts per turn will be $2 \times 2f \times \phi \div 10^8$ which gives average volts. If E is to equal effective volts, the average volts must be multiplied by 1.11 ($E_{eff} = 1.11 \times E_{av}$). Voltmeters read effective volts.

The constant K then becomes

$$K = \frac{2 \times 2 \times 1.11}{10^8} = \frac{4.44}{10^8} = 4.44 \times 10^{-8}$$

The entire formula for effective E including all of the factors referred to above is written

$$E = \frac{4.44\phi Nf}{10^8} \quad \text{or} \quad 4.44B_m A N f 10^{-8} \quad (39)$$

where B_{max} = maximum normal induction (flux) in maxwells per pole.

A = area of cross section of pole face in square centimeters.

N = number of turns of conductor.

$\phi = B_{max} \times A$.

Note 1: The factor f , which is derived from the frequency formula previously given, involves the number of pairs of field poles and the speed of rotation of the machine when rotating-field or rotating-armature alternators are considered. When the formula is applied to the inductor-type alternator the basic factors are the same although arrived at in a different way, and therefore K also includes these same equivalent factors.

Example: Suppose we have a 4-pole alternator running at a speed of 1,800 r.p.m.; the flux density is 15×10^4 lines; the number of conductors is 300. What is the voltage generated?

Solution: The frequency figures out to 60 c.p.s. and the e.m.f. formula may then be applied:

$$E = \frac{4.44\phi Nf}{10^8} = \frac{4.44 \times 15 \times 10^4 \times 300 \times 60}{10^8} = 119.8, \text{ or approximately } 120 \text{ volts}$$

Note 2: If the alternator in the preceding example was of the inductor type, the same method of figuring could be applied, as f is the figure for frequency in cycles per second and the type of alternator used is of no importance.

2.18. Effective Voltage and Current.—Since the voltage or current in an alternating-current system is actually of different instantaneous values throughout the time periods of the alternating cycle, and since the

cycles follow in rapid sequence per second of time, the actual *effective* voltage or current can only be determined by comparing the alternating-current heating effect with that of direct current.

This is known as the *effective* or *root-mean-square (r.m.s.)* value of an alternating current or voltage because, if the instantaneous values of current during a cycle of alternating current are taken, the results squared, and an average value obtained of these squared instantaneous currents, and then the square root of this value derived, the heating effect will be the same as in direct-current circuits, namely, proportional to the square of the current.

Hence the amplitude or peak factor of an alternating wave must be the ratio of its maximum value to its r.m.s. or effective value, or $\sqrt{2} = 1.414$.

Thus

$$E_{eff} \text{ or } E_{r.m.s.} = E_{max} \times 0.707 \quad \text{or} \quad \frac{E_{max}}{1.414} \quad (40)$$

and

$$E_{max} = E_{eff} \times 1.414 \quad \text{or} \quad \frac{E_{eff}}{0.707} \quad (41)$$

Most electrical indicating instruments read the effective-voltage or current values, and consequently the peak voltage or current may be readily obtained by multiplying the meter reading by 1.414.

Peak values, particularly for insulators and condensers, are of great importance since the stress to which a dielectric of a condenser is subjected depends upon the maximum value of the alternating-current charging voltage and not upon its r.m.s. or effective value.

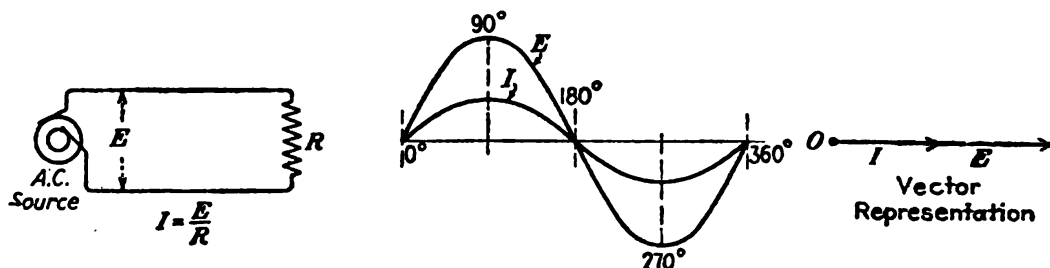


FIG. 2-12.—Relations in non-reactive circuit.

2.19. Effect of Resistance on Phase Relations.—Figure 2-12 illustrates the phase relationship of the voltage and current through the 360 degrees of a cycle in an alternating-current circuit which does not contain any inductance or capacity but simply ohmic resistance. The vector diagram shows that the voltage and current arms of the rotating vector are in phase, which in other words states that the current and voltage reach their instantaneous periods at the same time and, consequently, are said to be in phase with each other. Hence, $E = IR$ as in direct-current circuits.

2.20. Effect of Inductance on Phase Relations.—We have seen that an inductance possesses the property of inertia or mass which tends to prevent it from being set into motion and then, once in motion, will tend to prolong its motion. That is to say, the period in which the electrons in a circuit are being accelerated is representative of the work being done in creating a magnetic field around a coil or conductor. Thus, when the accelerating motion is decreased by lowering the source e.m.f. or increasing the resistance of a circuit, the energy stored up in the inductance in the form of a magnetic field is converted into kinetic energy $\frac{1}{2}LI^2$, thereby tending to prolong the movement of the electrons in the conductor. Thus, during the period in which the magnetic field is being expanded around the coil, the current flow will be momentarily opposed resulting in a lagging effect of the current behind the applied voltage. This condition is illustrated in Fig. 2-13 where the retarding effect acting

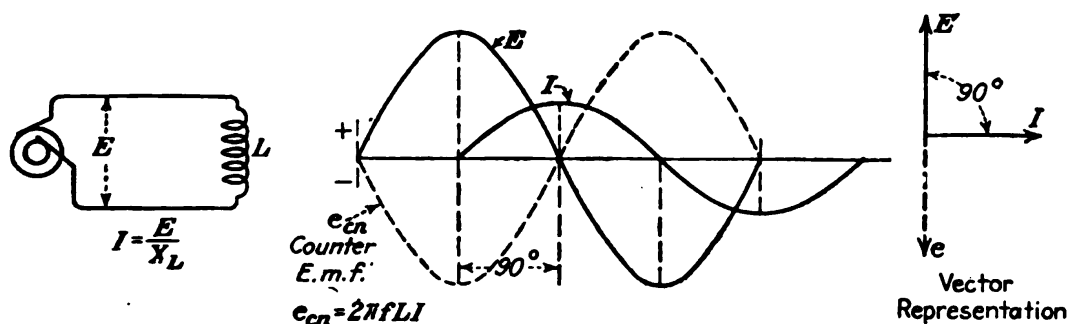


FIG. 2-13.—Relations in inductively reactive circuit.

against the current flow is called the inductive reactance X_L . This is expressed in ohms and represents the opposition offered to the flow of an alternating current just as does resistance in a direct-current or non-reactive alternating-current circuit. However, since the circuit contains both resistance and reactance (it is assumed that all inductances must have some direct-current resistance), the total opposition must be the result of their combined effects. This is known as the *impedance* of a circuit and is expressed by the letter Z .

If the alternating-current circuit contains pure inductance with absolutely no direct-current resistance, in either the coil or the circuit, the current flow will be 90 degrees behind the source e.m.f., owing to the opposing effect from the counter e.m.f. of self-induction. This condition is illustrated in Fig. 2-13. The current flow in this circuit may be determined by the ratio $I = E/X_L$, where X_L is the reactive effect in ohms.

The voltage induced in an inductance by a changing current is L times the rate of change of current. If at any time, t , the current is $i = I \sin \omega t$, where ω is the angular velocity or rate of change of angular displacement of the current vector, then the rate of change of the current is ω times the cosine of the angle ωt . This can be seen since the rate of change or slope is a maximum when the current goes through zero and

zero when it goes through maximum at 90 and 270 degrees. (See Fig. 2-13.) Thus the induced voltage or counter e.m.f. = $L\omega I \cos \omega t$. The current ($I \cos \omega t$) thus leads the counter e.m.f. by 90 degrees. The reactance is then

$$X_L = \frac{e}{i} = \omega L = 2\pi fL \quad (42)$$

Now, if we consider that all inductive circuits must contain some resistance and that the reactive and resistive effects are out of phase by 90 degrees, the total effective resistance, or the impedance of the circuit, cannot be obtained as a whole number by adding their respective ohmic values algebraically, but must be obtained by adding their respective values vectorially. In other words, we apply the right triangle to the

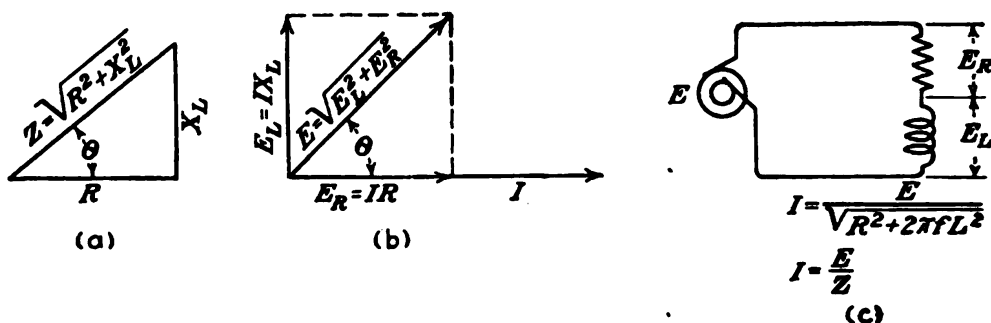


Fig. 2-14.—Vector representation of inductively reactive circuit containing resistance.

solution of this problem by using the base as the resistance, or R value, and the altitude as the X_L , or reactive value. The hypotenuse of the right triangle, therefore, will represent the impedance Z of the circuit and is obtained by taking the square root of the sum of the squares [Fig. 2-14(a)]:

$$Z = \sqrt{R^2 + X_L^2} \quad \text{ohms} \quad (43)$$

Consequently, since the reactance and the resistance effects are added vectorially, it is evident that the voltages across the inductance and the resistance must also be out of phase, and therefore the effective e.m.f. must also be a vectorial function. Hence, the effective e.m.f. may also be obtained by a right triangle as illustrated in Fig. 2-14(b):

$$E = \sqrt{E_L^2 + E_R^2} \quad (44)$$

where E_L = the e.m.f. across the inductance.

E_R = the e.m.f. across the resistance.

E = the source or the resultant e.m.f.

2.21. Effect of Capacity on Phase Relations.—The condenser, it has been seen, stores up energy in electrostatic form. During the period of charge the condenser is building up a potential difference which eventually equals the source e.m.f. After this, no more electrons will

be moved throughout the circuit. Now, if the applied potential is of an alternating-current characteristic, the condenser will charge from 0 to 90 and 180 to 270 degrees of the cycle and it will discharge through the circuit from 90 to 180 and 270 to 360 degrees of the cycle. That is to say the condenser is offering the maximum opposition to the source e.m.f. at the 90- and 270-degree periods and the least opposition at the beginning of the half-cycle periods. If, therefore, a condenser is permanently connected across an alternating-current source, a current will flow in the condenser circuit for each reversal of source potential. This current is the rate of flow of the charge established in the condenser. As shown before, the voltage across a condenser equals q/c . The current, then, equals the rate of change of voltage multiplied by the capacity.

As shown previously in the case of current, the rate of change of a voltage e ($= E \sin \omega t$) is equal to $\omega E \cos \omega t$. The factor $E \cos \omega t$ is equal to the original voltage, e , advanced 90 degrees. Hence, $i = C \omega e$ or

$$\frac{e}{i} = X_c = \frac{1}{\omega C} = \frac{1}{2\pi f C} \quad (45)$$

where C is in farads and f is in cycles per second.

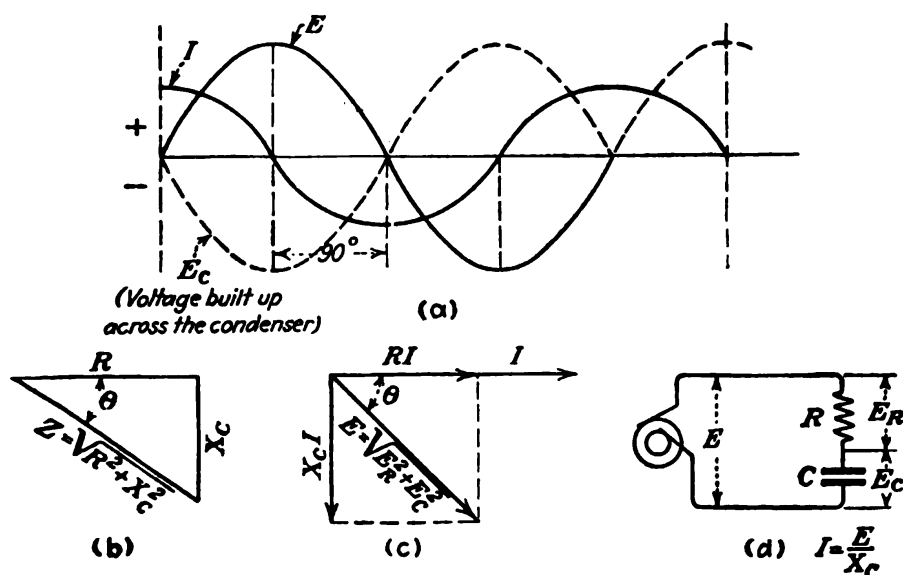


FIG. 2-15.—Vector and phase representation of capacitively reactive circuit containing resistance.

However, since all capacities are generally in micro-units or microfarads, the formula may be more conveniently expressed

$$X_c = \frac{1,000,000}{2\pi f C} \quad \text{ohms} \quad (46)$$

where C is in microfarads.

Figure 2-15(a), (b), and (c) illustrates the *leading* effect of the current ahead of the e.m.f. at the various points of the cycle. If the condenser,

or the circuit in which it is connected, contains no direct-current resistance, the current will lead the voltage by 90 degrees and

$$I = \frac{E}{X_c} \quad (47)$$

If, on the other hand, resistance is to be included in the calculation, the expression for impedance must again be used, namely,

$$I = \frac{E}{Z} \quad (48)$$

Thus it can readily be seen that in all forms of reactive circuits, either inductive or capacitive, which contain resistance, the current and voltage relationships in terms of *lead* or *lag* may be determined by the phase angle θ , expressed trigonometrically, $\cos \theta$. In other words, it is possible to determine the exact number of degrees between 0 and 90 degrees that a voltage or current will lead or lag, as the case may be, owing to the resistance in the circuit. Expressed mathematically, the angular difference may be obtained by any of the following relations:

$$\cos \theta = \frac{R}{Z} \quad (49)$$

$$\sin \theta = \frac{X}{Z} \quad (50)$$

$$\tan \theta = \frac{X}{R} \quad (51)$$

2.22. Power Factor.—In alternating-current engineering the equation (49) is known as the *power factor* of a circuit and is used to indicate the exact ratio in percentage between any two sinusoidal waves of either current, voltage, or both, relative to each other.

Example: Assume the source voltage in Fig. 2-15(d) to be 120 volts at 60 cycles; the resistance R , 15 ohms; and the condenser C , 25 mf. What is the power factor and the angle of lead in degrees?

Solution:

$$X_c = \frac{1,000,000}{2\pi fc} = 106\omega$$

$$Z = \sqrt{R^2 + X_c^2} = \sqrt{15^2 + 106^2}$$

$$Z = \sqrt{225 + 11,236} = 107$$

Answer:

$$\text{Power factor} = \frac{R}{Z} = \frac{15}{107} = 0.14$$

The angle whose cosine = 0.14 is 82 degrees (see any table of natural sines and cosines).

Hence the current in this example leads the voltage by 82 degrees.

2.23. Ohm's law adapted for alternating-current circuits containing reactive and resistive properties may thus be expressed by the ratio

$$I = \frac{E}{\sqrt{X_{L \text{ or } C}^2 + R^2}} = \frac{E}{Z} \quad (48)$$

$$Z = \frac{E}{I} \quad (52)$$

$$E = IZ \quad (53)$$

Example: The circuit in Fig. 2-14(c) contains a direct-current resistance of 4 ohms and an inductance of 680 mh. The alternating-current effective e.m.f. is 500 volts at a frequency of 120 cycles. Find the value of the current flowing in the circuit.

Solution:

$$X_L = 2\pi fL = 2 \times 3.14 \times 120 \times 0.68 = 512 \text{ ohms}$$

$$R = 4 \text{ ohms}$$

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{16 + 262,308} = 512 \text{ ohms}$$

Answer:

$$I = \frac{E}{Z} = \frac{500}{512} = 0.97 \text{ amp.}$$

It can be clearly seen from this example that the current flow will be practically dependent upon $I = E/X_L$, if the direct-current resistance is very low. For practical purposes this ratio may be sufficient, but in cases where rigid accuracy is desired the impedance function must be maintained.

2.24. Series Circuit Analysis.—A general series circuit, containing resistance, capacitance, and inductance, together with a vector analysis of

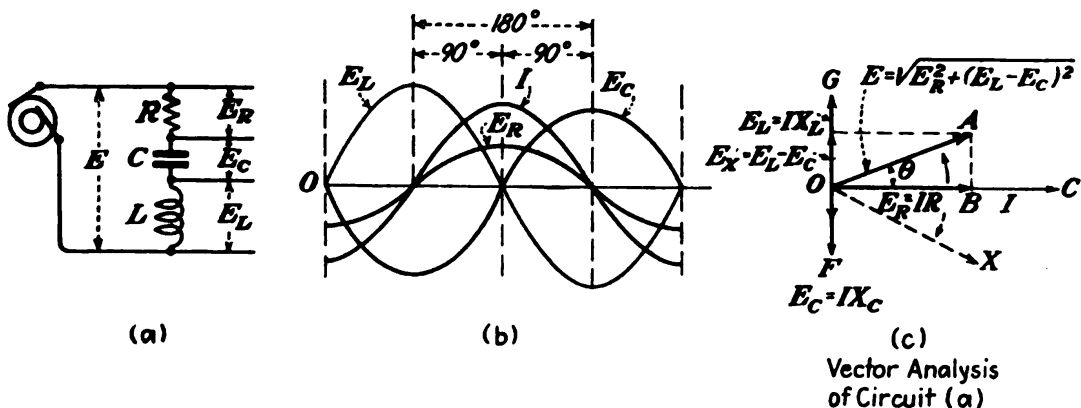


FIG. 2-16.—Vector and phase representation of series-impedance circuit.

its current and voltage relations, is illustrated in Fig. 2-16(a), (b), and (c). We have seen that the voltage across an inductance and a capacity in a single inductive or capacitive circuit will always be out of phase with the current flow in the circuit. The voltage and current across a resistance, however, will be in phase. Now, if an inductance, a capacity, and a resistance are connected in series with each other the phase relations

between each component part of L , C , and R will be as illustrated in Fig. 2-16(b) and (c).

The current flow in a series circuit is the same at any portion of the circuit and may be conveniently expressed by the horizontal line OC in Fig. 2-16(c). The e.m.f. across the resistance ($E_R = IR$) is measured by the vector OB which coincides with the direction of OC . That is to say, they both move together, since the voltage and current in a resistive circuit are in phase. The e.m.f. of self-induction built up across the inductance E_L is represented by the vector arm OG and is shown at right angles to the current to indicate that the current due to the inductance is lagging by 90 degrees behind the e.m.f. Similarly, the e.m.f. built up across the condenser E_C is represented by the vector arm OF , also at right angles to the current but in the opposite direction, to show that the current in the condenser is leading the e.m.f. by 90 degrees.

The vector sum of the reactance voltages E_L and E_C is equal to the vector E_X , which is equal to their arithmetical difference, since the two voltages are exactly 180 degrees out of phase. The voltage across the three components, E , is then the resultant of E_X and E_R as shown.

It can be seen that since the inductive reactance is greater than the capacitive reactance, the voltage E leads the current I and, conversely, the current lags the voltage, which means the circuit acts as an inductance. If the inductive and capacitive reactances just cancel each other, the circuit would show an impedance equal to the resistance R , and the circuit would be said to be resonant. If the capacitive reactance was greater, the resultant would be in a position such as OX , and the phase angle θ would be in the opposite direction, indicating that the current leads the voltage by a certain number of degrees. This means that the circuit acts as a capacitance.

Hence the triangle OBA may be expressed mathematically

$$E = I \sqrt{R^2 + (X_L - X_C)^2} = IZ$$

Thus,

$$Z = \sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2} = \sqrt{R^2 + X^2}$$

Therefore,

$$I = \frac{E}{\sqrt{R^2 + X^2}} = \frac{E}{Z}$$

A practical example may be applied to Fig. 2-16(a) in which the source frequency f is 120 cycles; the resistance R , 20 ohms; the inductance L , 2 henrys; and the condenser C , 10 mf. A current of 3 amp. is flowing in the circuit.

Example: Calculate the following:

- (a) The e.m.f. across the component parts R , C , and L .
- (b) The applied e.m.f. E .
- (c) The circuit impedance Z .
- (d) The power-factor cosine θ .

Solution:

$$\begin{aligned}
 X_L &= 2\pi \times 120 \times 2 = 1,507 \text{ ohms} \\
 X_C &= \frac{1,000,000}{2\pi \times 120 \times 10} = 133 \text{ ohms} \\
 (a) \quad E_R &= I \times R = 3 \times 20 = 60 \text{ volts} \\
 E_C &= I \times X_C = 3 \times 133 = 399 \text{ volts} \\
 E_L &= I \times X_L = 3 \times 1,507 = 4,521 \text{ volts} \\
 (b) \quad E &= \sqrt{E_R^2 + (E_L - E_C)^2} \\
 E &= \sqrt{60^2 + (4,521 - 399)^2} = 4,122.4 \text{ volts} \\
 (c) \quad Z &= \sqrt{R^2 + (X_L - X_C)^2} \\
 &= \sqrt{20^2 + (1,507 - 133)^2} = 1,374 \text{ ohms} \\
 (d) \quad \text{Power factor} &= \cos \theta = \frac{R}{Z} = \frac{20}{1,374} = 0.0145 \\
 &\quad \theta = 89 \text{ degrees} \\
 \text{or} \quad \text{Power factor} &= \cos \theta = \frac{P}{E \times I} = \frac{\text{true power}}{\text{volt-amperes}}
 \end{aligned}$$

Hence the inductance in this circuit predominates, and the current lags behind the e.m.f. by a phase difference of 89 degrees.

2.25. Parallel Circuit Analysis.—Figure 2-17 (a) shows the general parallel circuit containing resistance, inductance, and capacitance. Figure 2-17 (b) gives the vector relations of the various currents to the applied voltage.

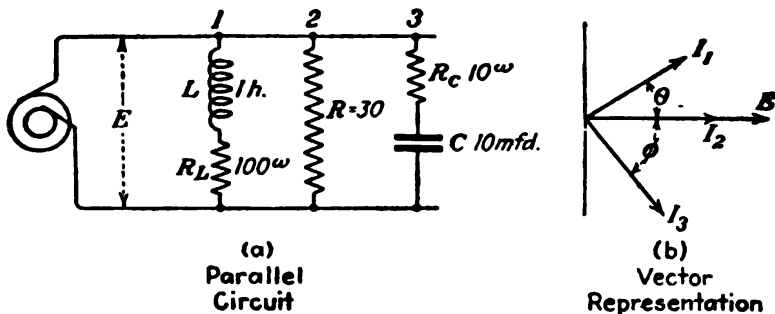


FIG. 2-17.—Parallel impedance branches.

In the analysis of parallel circuits it is convenient to use the concepts of conductance, G , which is the reciprocal of resistance as previously shown; susceptance, B , which is the reciprocal of reactance; and admittance, Y , which is the reciprocal of impedance.

When there are a number of components in parallel, the total conductance is equal to the sum of the conductances in each branch,

$$G = g_1 + g_2 + g_3 \dots \quad (54)$$

Reactances are vector quantities, however, and their inductive and capacitive reactances have opposite signs, inductive reactance being assumed positive and capacitive reactance negative. When the reciprocals are taken the signs are reversed, so that the susceptance of an

inductance is negative, and that of a capacitance is positive. Keeping this relation in mind, then, the total susceptance of a number of parallel reactances may be found by their algebraic sum,

$$B = b_1 + b_2 + b_3 \dots \quad (55)$$

The admittance, Y , is related to the conductance and susceptance by the equation

$$Y = \sqrt{G^2 + B^2} \quad (56)$$

In a series circuit containing both resistance and reactance the conductance and susceptance are found by the formulas,

$$G = \frac{R}{Z^2} \text{ mhos} \quad (57)$$

$$B = \frac{X}{Z^2} \text{ mahos} \quad (58)$$

Thus it can be seen that the susceptance of a reactive circuit is equal to the reciprocal of the reactance only when the resistance in series equals zero. Therefore, in analyzing the parallel circuit it is necessary first to find G and B for each branch and from that to find Y . The unknown currents and voltages can then be determined.

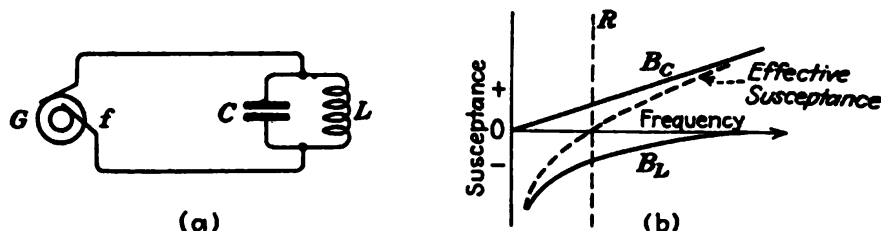


FIG. 2-18.—Parallel resonant circuit.

Example: Assume the applied frequency in Fig. 2-18(a) to be 60 cycles at a source e.m.f. of 220 volts. The inductance has a value of 1 henry with a direct-current resistance of 100 ohms. The condenser has a value of 10 mf. and a series resistance R_c of 10 ohms. The non-reactive resistance R has a value of 30 ohms. Find the following:

- The individual component impedances Z_1 , Z_2 , and Z_3 .
- The individual component currents I_1 , I_2 , I_3 .
- The individual component conductances g_1 , g_2 , g_3 .
- The individual component susceptances b_1 , b_2 , b_3 .
- The admittance Y .
- The impedance Z .

Solution:

- Branch reactances and impedances:

$$Z_1 \sqrt{R^2 + X_L^2} = \sqrt{10,000 + 141,978.24} = 390\omega \text{ (approx.)}$$

$$Z_2 = 30 \text{ ohms}$$

$$Z_3 = \sqrt{R^2 + \left(\frac{1,000,000}{2\pi f C}\right)^2} = \sqrt{100 + 70,225} = 265\omega \text{ (approx.)}$$

(b) Branch currents:

$$I_1 = \frac{E}{Z} = \frac{220}{390} = 0.56 \text{ amp.}$$

$$I_2 = \frac{E}{R} = \frac{220}{30} = 7.3 \text{ amp.}$$

$$I_3 = \frac{E}{Z} = \frac{220}{265} = 0.83 \text{ amp.}$$

(c) Branch conductances:

$$g_1 = \frac{R_L}{Z_1^2} = \frac{100}{152,100} = 0.0007 \text{ mho}$$

$$g_2 = \frac{R_2}{R_2^2} = \frac{30}{900} = 0.033 \text{ mho}$$

$$g_3 = \frac{R_c}{Z_3^2} = \frac{10}{70,225} = 0.00014 \text{ mho}$$

(d) Branch susceptances:

$$b_1 = \frac{X_1}{Z_1^2} = \frac{376.8}{152,100} = 0.0024 \text{ mho}$$

$$b_2 = 0$$

$$b_3 = \frac{X_2}{Z_3^2} = \frac{265}{70,225} = 0.0038 \text{ mho}$$

Hence the total susceptance:

$$B = b_1 + b_3 = - (0.0024) + (0.0038) = 0.0014 \text{ mho}$$

Note: b_2 is zero because the current in this branch is in phase with E .

(e) Admittance:

$$Y = \sqrt{G^2 + B^2} = \sqrt{0.0338^2 + 0.0014^2} = 0.034 \text{ mho (approx.)}$$

(f) Impedance:

$$Z = \frac{1}{Y} = \frac{1}{0.034} = 30 \text{ ohms (approx.)}$$

2.26. Series Resonance.—Electrical resonance is that condition encountered in a series oscillatory circuit when the inductive and capacitive reactances are equal and balance each other so that their reactive effect upon the circuit will be zero. Since an inductive reactance introduces a lagging effect, and a capacitive reactance a leading effect on the current with respect to the e.m.f., the resultant current flow will be dependent only upon the direct-current resistance in the circuit. Therefore, since the current and voltage across the direct-current resistance are always in phase with each other, the current flow in a series-resonant circuit will be $I = E/R$.

It may thus be readily seen that if the impedance in a series-resonant circuit is dependent upon $X_L = X_C$, then, by substituting and equating $2\pi fL = 1/2\pi fC$ and solving for the frequency, it would be possible to

determine the resonant frequency for any value of L and C in a series-resonant or parallel-resonant circuit by the formula

$$f = \frac{1}{2\pi \sqrt{LC}} \quad \text{cycles,}$$

$$\left(L = \frac{1}{4\pi^2 f^2 C} \quad \text{henrys,} \quad C = \frac{1}{4\pi^2 f^2 L} \quad \text{farads} \right) \quad (59)$$

where L and C are expressed in henrys and farads, respectively.

Since all capacities are in microfarads, and inductance in either micro-, milli-, or unit henrys, the frequency formula may be simplified considerably by using the proper numerator to fit the desired condition. For example, if it is desired to determine the resonant frequency of a series-resonant circuit in which both L and C are in microhenrys and microfarads, respectively, then the formula may be expressed:

$$f = \frac{1,000,000}{2\pi \sqrt{LC}} \quad \text{cycles,} \quad \left(L = \frac{1}{4\pi^2 f^2 C} \quad \text{henrys,} \quad C = \frac{1}{4\pi^2 f^2 L} \quad \text{farads} \right) \quad (60)$$

If, on the other hand, the inductance and capacity are in henrys and microfarads, respectively, then the formula may be expressed

$$f = \frac{1,000}{2\pi \sqrt{LC}} \quad \text{cycles} \quad (61)$$

Equation (60) is the general formula for determining resonant frequency, while Eq. (61) is generally used for high-frequency radio circuits and Eq. (62) for low-frequency and filtering circuits.

Example: Assume L and C in Fig. 2-16(a) to have a value of 15 henrys of inductance and 4 mf. of capacity. At what frequency is this circuit resonant?

Solution:

$$f = \frac{1,000}{2\pi \sqrt{LC}} = \frac{1,000}{6.28 \sqrt{60}} = \frac{1,000}{48.67} = 21 \text{ cycles}$$

It will be noted that the circuit resistance is not introduced into this formula. In general practice, R need not be considered if the ratio $4 \times L/C$ is great compared with the value of R^2 .

2.27. Parallel Resonance.—Parallel-resonant circuits are perhaps the most commonly used in radio transmitting and receiving circuits. An understanding of their functioning is of great importance for a thorough understanding of radio circuits.

It has been shown previously that the susceptance (reciprocal of reactance) of a parallel circuit is equal to the sum of the susceptances of the branches, and that the susceptances of an inductance and capacitance are opposite in sign. Since the impedance of an inductance increases linearly with frequency and that of a capacity varies inversely with frequency, it follows that there must be some frequency at which the reactance of an inductance will be equal and opposite to that of any capacitance. At this frequency the susceptances of the two impedances in parallel will cancel and the admittance, Y , will be zero if the conduct-

ance is zero. This is shown in Fig. 2-18 (b) and means that the impedance is infinite. Consequently the susceptance is zero, which is an obviously impossible condition since any inductance must have some resistance and hence some conductance. From this we get the formula:

$$\text{Parallel impedance at resonance} = \frac{(2\pi f_0 L)^2}{R_s} \quad (62)$$

where f_0 = frequency at resonance

R_s = reactance of the series loop

In a circuit such as shown the lagging current flowing through the inductance at very low frequencies is much greater than the leading current through the condenser, and the impedance characteristic is that of an inductance. At very high frequencies the current flows almost entirely through the condenser, and the circuit acts as a capacitance. Near the resonant frequencies the current in the two branches is nearly equal in magnitude and opposite in direction, so most of the current flows around the loop, and little of it in the main circuit. At resonance when the reactive currents are equal, the only current supplied by the generator is that supplied to compensate for the power lost in the resistance of the series loop.

2.28. Power Relations in Alternating-current Circuits.—It has been shown that the true power in any circuit in which the current and voltage are in phase is the product of $E \times I$ or $I^2 \times R$. That this power is available for heating, lighting, and operating machinery is apparent. However, in alternating-current reactive circuits, the true power cannot possibly be the product of $E \times I$, since the current and voltage are not in phase with each other. That is to say, the reactive parts of the circuit, such as the inductance or the capacity, actually return energy to the supply owing to conversion from potential to kinetic energy. Consequently, the true power in an alternating-current circuit must be dependent upon the ratio of the resistance component to the impedance component of the circuit as well as the product of EI , or the apparent power component. Hence, for single-phase circuits:

$$\text{True power} = \text{apparent power} \times \frac{\text{resistance}}{\text{impedance}}$$

or

$$\text{Power} = E \times I \times \frac{R}{Z} \quad \text{watts} \quad (63)$$

Furthermore, since the ratio R/Z in a right triangle is called the cosine of an angle, or $\cos \theta$, and also the *power factor*, the power formula may be similarly expressed

$$\text{Power} = E \times I \times \cos \theta \quad \text{watts}$$

Figure 2-19 illustrates the power curve in an alternating-current circuit containing inductance.

It will be noted that the power curve falls to zero at the points at which the current or voltage is zero. That is to say, at any instant when either the voltage or current is at zero the instantaneous power will also be zero. Obviously, therefore, since the current and voltage do not reach the zero points of the cycle in a reactive circuit simultaneously or in phase, the peak power must lie at some point between their respective zero points. The effective power $EI \cos \theta$ must depend upon the energy expended in the circuit during the cycle.

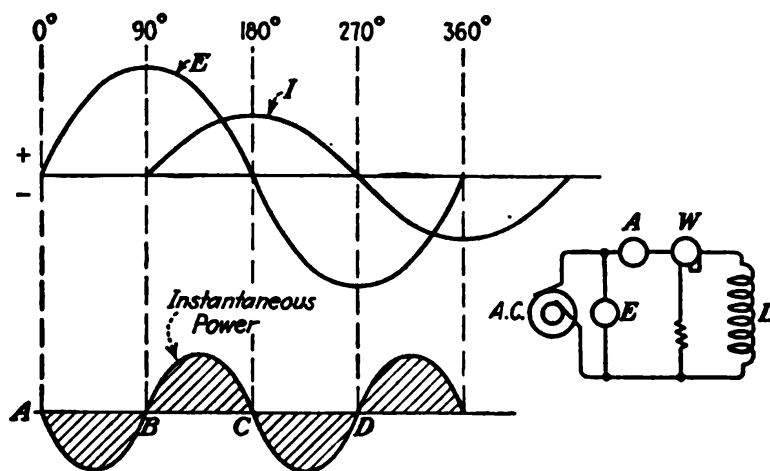


FIG. 2-19.—Voltage, current, and power relations in an alternating-current circuit.

It will be noted that the frequency of the power curve is twice that of the current; also, that the power portion of the curve below the horizontal axis at the points AB and CD represents the amount of energy returned to the circuit by the kinetic energy of the collapsing magnetic field.

The condition of power expenditure as just explained applies to common alternating-current circuits of a sinusoidal character and does not apply to waves of a non-sinusoidal character.

2.29. Kilovolt-amperes.—The rating of alternating-current machinery, such as transformers and alternators, depends upon the amount of heat the windings can stand. The amount of flux produced is dependent upon the voltage and current in the windings and is independent of phase relations. It is logical, therefore, that the power factor should be neglected in computing the load an alternating-current device can carry, and this is done. These machines when used in power and lighting installations are rated in kilovolt-amperes, which is a direct measure of the heating factors in the windings and a true measure of the capacity of the machine to do work. Radio equipment is usually rated in kilowatts. The abbreviation for kilovolt-amperes is kva. Thus,

$$\text{Power rating} = E \times I \div 1,000 \text{ kilovolt-amperes} \quad (64)$$

2.30. Polyphase Alternating-current Circuits.—As the only polyphase circuits in common use today are of the three-phase system, our discussion will be centered on three-phase equipment.

If a revolving-field alternator has three equispaced armature windings, as shown in the elementary diagram (Fig. 2-20), the induced voltage will be of a three-phase characteristic, each phase following the other by 120 degrees, as shown in Fig. 2-21. This machine, as connected to the

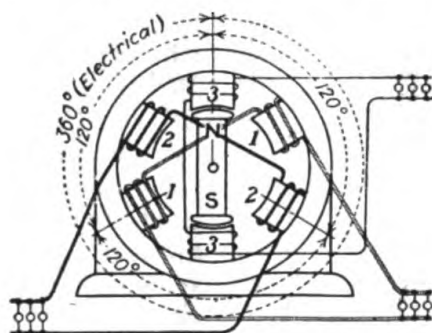


FIG. 2-20.—Revolving-field alternator.

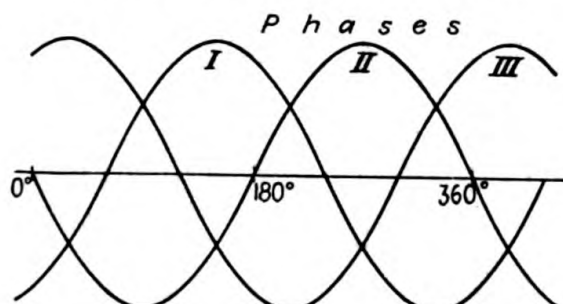


FIG. 2-21.—Voltage relations in a three-phase system.

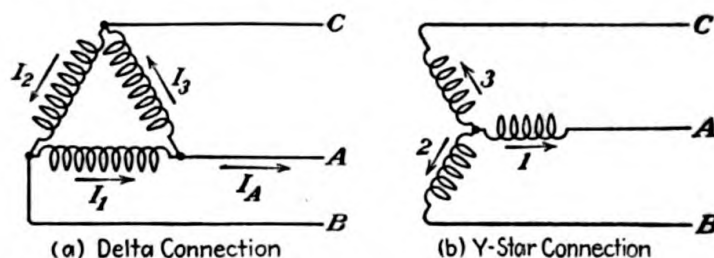


FIG. 2-22.—Schematic methods of connecting coils to a three-phase system.

load shown in the figure, is a simple balanced three-phase system. Such a generator would require six terminals, two for each phase, and is now obsolete. Other methods of connection, called the *delta* and *star* systems, are now employed which make only three terminals necessary on the apparatus. The star system of connection is also called the *Y* or *wye* method. These systems are illustrated in the diagrams of Fig. 2-22.

Current and voltage relations in a three-phase alternator depend upon the method of connection employed, that is, whether it is delta (also called *mesh*) or *Y* connected.

Delta- or Mesh-connected Alternator.—a. The scheme of armature-coil connection for this circuit is shown in Fig. 2-22(a). The windings in the machine are not, of course, arranged in the position shown in the diagram, but the electrical circuit is schematically as shown. In an actual machine it is very difficult to tell the method of connection employed, as to do so requires penetration of the insulating wrapping around the windings which is sometimes a very difficult operation.

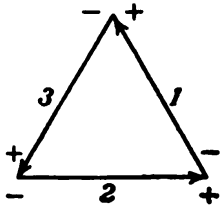


FIG. 2-23.—Voltage relations in a delta connection.

b. In a delta-connected machine the voltage relations in coils 1, 2, and 3 may be shown vectorially as in Fig. 2-23. Note that no current can circulate in the armature because the voltage drop across each coil is exactly balanced by the combined voltage drop of the other two coils. However, if three lines are taken off the armature and lettered A, B, and C, as shown in Fig. 2-22(a), an e.m.f. will exist between certain points in the three-wire system as will be seen from the following consideration.

c. The voltage between any two lines must obviously be equal to the voltage generated in the coil across which they are connected.

d. The vector relations of the various voltages and currents are shown in Fig. 2-24. The generated voltages are shown, E_2 lagging E_1 by 120 degrees, and E_3 lagging E_2 by 120 degrees. It can be seen that the vector sum of voltages E_2 and E_3 just equals $-E_1$, so that the resultant voltage in the loop, and hence the circulating current, is zero.

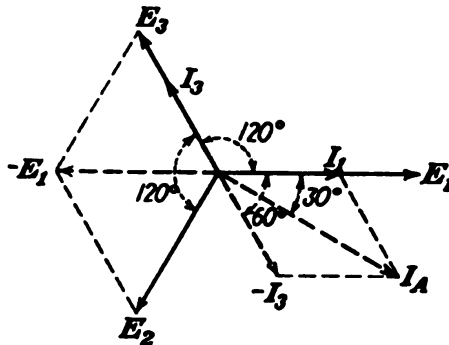


FIG. 2-24.—Vector representation of voltage and current relations in a delta connection.

e. The current in each winding is assumed to be in phase with the voltage. Then the current I_A in line A equals the vector sum of I_1 and $(-I_3)$ since the current I_3 is assumed to be in the opposite direction. By simple trigonometry, as shown in Fig. 2-24,

$$I_L = 2 \times I_2 \cos 30^\circ = \sqrt{3} \times I_2$$

or

$$I_L = \sqrt{3} \times I_\phi \quad \text{or} \quad 1.73 \times I_\phi$$

where I_ϕ is the current in each phase and I_L the current in each line. To the practical man not familiar with trigonometry the relationship may be expressed:

$$\text{Line current } I_L = 1.73 \times I_\phi \quad (65)$$

f. It will be seen by studying Fig. 2-24 that, while each phase current is in phase with the e.m.f. which produces it, the total line current I_L and the phase currents producing it are separated by a 30-degree phase angle.

Y or Star Connection.—a. This method of connection is shown in Fig. 2-22(b), where three like ends of coils 1, 2, and 3 are connected together, and the free ends are connected to the three line wires. The voltages in the armature windings 1, 2,

and 3 are shown in the vector diagram Fig. 2-25. As the phase angle between the voltage and current in each phase is the same, this same figure can also represent the current relationship in the three phases. For example, the voltage in coil 2 is always 120 degrees behind that in coil 1, and the voltage of phase 3 is 120 degrees behind phase 2. This is vectorially shown by the lines 1, 2, and 3 in Fig. 2-25. Also, in this same figure, line 2 properly shows the 120-degree difference between phase 2 and phase 1, similarly between phase 3 and phase 2.

b. Referring back to the schematic diagram of a Y-connected alternator, Fig. 2-22(b), it is seen that the current in line *A* must come from coil 1, that in line *B* from coil 2, and that in line *C* from coil 3. The word *coil*, as used here, and as shown in the diagrams, means an entire phase winding.

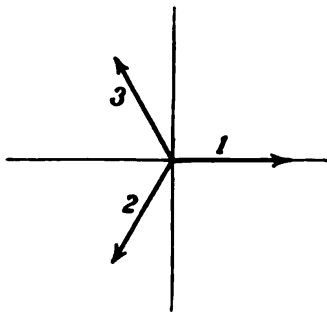


FIG. 2-25.—Voltage relations in a star connection.

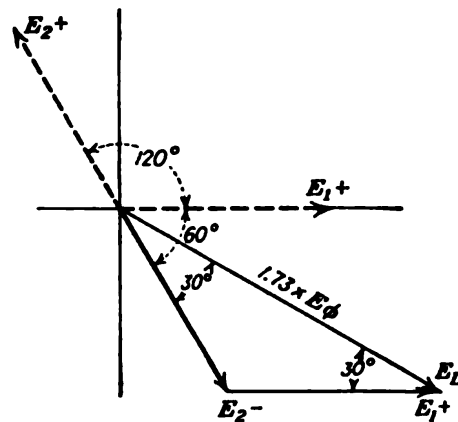


FIG. 2-26.—Vector representation of voltages in a star connection.

c. The e.m.f. across any phase of the line is the algebraic sum of the e.m.fs. produced by the two phase windings across which the line is connected. For example, in the Y-connected alternator [Fig. 2-22(b)], the e.m.f. across lines *A* and *B* must be produced by coils 1 and 2 because these are the only two coils in the circuit. Now, if the relative direction of the e.m.f. in each coil is as is indicated by the arrows in the figure, we may plot a vectorial diagram of the total voltage in each phase as shown in Fig. 2-26. Here it is seen that the e.m.f. produced by coil 1 is plotted as vector line E_1 . If we assume the voltage E_1 to be positive when it forces current toward line *A*, the voltage in coil 2 must be negative as shown. Thus the line voltage must be E_1 added vectorially to $(-E_2)$. This is shown in Fig. 2-26, giving the vector voltage E_L .

Expressed mathematically,

$$E_L = 2E_1 \times \cos 30^\circ = \sqrt{3} \times E_\phi = 1.73 \times E_\phi \quad (66)$$

where E_L is the voltage across the line E_1 , and E_ϕ is the voltage in one phase.

Summary.—Voltage and current relations in a three-phase system may be summarized as follows:

a. In any three-phase system the voltage across any one phase has a phase-angle relationship of 120 degrees to the voltages in the other two phases.

b. In a balanced delta- or mesh-connected system the voltage across any line of the system equals the e.m.f. across any armature winding or belt in the alternator, $E_L = E_\phi$. The current in each line equals 1.73 times the current in each armature winding, $I_L = 1.73 \times I_\phi$.

c. In a balanced Y- or star-connected system the current across any line of the system equals the current in the armature path to which the line is connected, $I_L = I_\phi$. The voltage in each line equals 1.73 times the voltage summation of the armature windings to which the line is connected, $E_L = 1.73 \times E_\phi$.

2.31. Power in a Three-phase System.—In a simple three-phase balanced circuit, as shown in Fig. 2-20, the power in the circuit would be

$$P = 3 \times E_\phi \times I_\phi \times \cos \theta \quad \text{watts} \quad (67)$$

where E_ϕ = the phase voltage.

I_ϕ = the phase current.

$\cos \theta$ = the angle between E and I , or the power factor.

However, in a delta-connected machine,

$$I_\phi = \frac{I_L}{1.73} \quad \text{and} \quad E_\phi = E_L$$

and in a Y- or star-connected machine

$$E_\phi = \frac{E_L}{1.73} \quad \text{and} \quad I_\phi = I_L$$

Consequently, power in a delta- or Y-connected machine is

$$P = 1.73 \times E_L \times I_L \times \cos \theta \quad \text{watts} \quad (68)$$

where E and I are line voltage and current, respectively.

Example: A three-phase transformer is connected across a three-phase line in which each phase draws 10 amp. The voltage across each phase is 220 volts. The power factor is 0.85. What are the true and apparent power in the circuit.

Solution: True power = $1.73 \times 220 \times 10 \times 0.85 = 3,235$ watts.

Apparent power = $1.73 \times 220 \times 10 = 3,806$ watts or 3.8 kva.

CHAPTER 3

INTRODUCTION TO RADIO TUBES AND CIRCUITS

The diode or two-element vacuum tube is the simplest vacuum tube in use. It consists of a *cathode* and a *plate*. The cathode may be a filament or it may be an indirectly heated electron-emitting material. In construction the diode is identical to the three-element tube, shown in Fig. 3-1, with the grid omitted. The tube shown in Fig. 3-2 is a diode.

The diode just mentioned is a simple rectifier, and as such its action will be explained in Sec. 6.5. Diodes are also made with one cathode and two plates for use as a full-wave rectifier, and with two cathodes and two plates (twin diode) for use as detectors and low-voltage rectifiers and in automatic volume control circuits.

The triode or three-element vacuum tube as used in radio communication consists of a filament, a grid, and a plate, all sealed in an evacuated bulb, which is provided with the necessary external terminals for making contacts with the three elements inside. A study of the fundamentals of the triode will give an understanding of vacuum-tube operation on which a knowledge of the action of the tetrode, pentode, and similar multielement tubes can be built. For this reason, therefore, the triode will first be studied in considerable detail; a study of other types of tubes will then follow logically.

I. VACUUM-TUBE CHARACTERISTICS

3.1. The filament is simply a thin wire made up of a special composition which becomes heated when a current flows through it. Some filaments must be heated to incandescence (white hot) for the best results, while others perform even more satisfactorily when operating at a dull-red temperature. The two most important types of filaments used in the modern radio vacuum tube are thoriated tungsten and platinum coated with oxides of barium and other elements. The former usually operates best when the filament is white hot, while the latter operates most efficiently when in a state of dull or cherry red. The filament may be looked upon as a substance which evaporates when heated and then gradually disappears. This may be very readily understood if we use water as an analogy for evaporation. For example, at ordinary temperatures water is known to evaporate very slowly, but, as it becomes heated, more and more evaporates until finally there is a violent boiling and the water is transformed into steam and passes into the atmosphere.

Similarly, when the filament in a vacuum tube is heated to operating temperature, the small particles of matter (electrons) which make up the physical structure of the filament are gradually escaping into space.

It has been shown that all substances are composed of infinitely minute particles of matter called *molecules*, and that these molecules in turn are made up of still smaller particles called *atoms*. Now, at ordinary temperatures, these small bodies are constantly colliding with one another, and consequently, if the temperature is raised, the motions of these molecules speed up and they start to bombard their neighbors with such tremendous velocity that the surface tension, due to the forces of cohesion between the atoms of a solid, is diminished, and some of the free electrons in the materials may actually be forced beyond the surface of the material and ejected into space. It can readily be seen that this action may produce in the immediate vicinity of the filament a vapor, or cloud, similar to the evaporation of the water when boiling. This cloud is found to be in the form of a negative state of electricity due to the fact that the entire area near the filament is made up of the free electrons which have broken through the surface of the material. The reader must, therefore, always picture the immediate vicinity of the filament, when it is heated to operating temperature, as an atmosphere charged with electrons or negative particles of electricity.

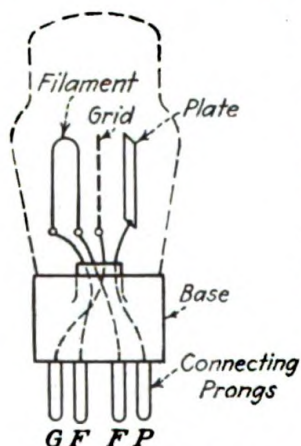


FIG. 3-1.—Three-element vacuum tube (triode).

This ever present negative charge (called *space charge*) or field in the immediate vicinity of the heated filament gives rise to one of the most important fundamentals in vacuum-tube theory. As stated before, if a positively charged body is placed in the vicinity of a negatively charged body, an attraction will result. In other words, electrons will move in the direction of the positively charged body. Now, if we apply this principle to the vacuum tube, let us see what happens when a positive charge is placed on a metal plate located near the filament inside of the vacuum tube.

Figure 3-1 illustrates the construction of a simple vacuum tube. Figure 3-2(a) illustrates the effect obtained in the immediate vicinity of the filament, when no positive potential is applied to the plate (plate switch open). Note the cloud of electrons in the vicinity of the filament.

The function of battery A is merely to apply a voltage pressure across the filament terminals to force a current to flow through the filament to produce the necessary heating effect. This pressure may be supplied by a battery, generator, or a transformer, provided the proper value of voltage is applied. Too much voltage may cause an excessive amount of current to flow through the filament and consequently cause it to evaporate too quickly or, in other words, to burn out. Every tube must operate at the proper voltage as specified by the manufacturer.

It will be seen from Fig. 3-2(a) that no electrons are attracted to the plate, because the plate potential is not applied and therefore the electrons concentrate around the vicinity of the filament. However, as soon as the plate-circuit switch is closed [Fig. 3-2(b)], a positive potential will be

applied to the plate which causes the electrons to be drawn over (attracted) to the plate. This is called the *Edison effect* and gives rise to an electron flow in the plate circuit in the direction of the arrows as illustrated in Fig. 3-3.

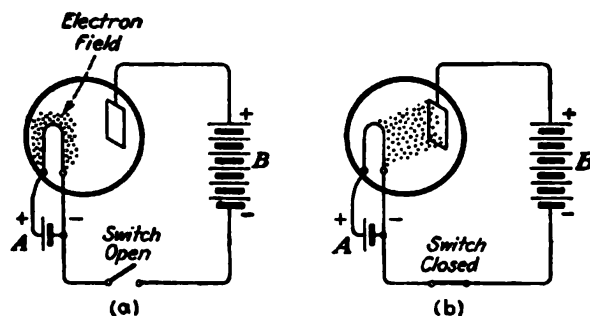


FIG. 3-2.—Diagrams to illustrate the effects of the space charge in a vacuum tube.

3.2. Effect of Plate Potential on Plate Current.—The filament sends forth its electrons at a certain rate, depending upon the potential of the plate itself in respect to the filament and upon the degree of heat at which the filament is burning. It is easily conceivable that there will be a point, assuming that the plate has a high potential, when it will be attracting all of the electrons which leave the filament. When this happens, an increase in plate potential cannot result in a heavier electronic flow from the filament because all of the electrons leaving the filament are already reaching the plate. Hence, increasing the plate potential beyond this point will not result in a larger plate current. (Remember, the amount of current flowing in the plate circuit is governed absolutely by and really is the electronic stream from the filament to the plate.) This is known as the *saturation point*, and the electronic stream cannot be increased beyond this point.

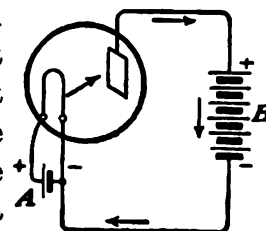


FIG. 3-3.—The arrows indicate the direction of electron (current) flow in a vacuum tube.

Now then, let us assume that the filament is burning at its rated brilliancy and sending forth a maximum number of electrons. Assume the plate potential to be adjusted low at this particular instant. It will be readily seen that all the electrons leaving the filament will not be attracted to the plate: first of all, because the plate potential is not sufficiently high to draw them all over, and second, because the electrons have a tremendous repelling tendency. In other words, some of the electrons leaving the filament are constantly repelled, thus leaving a certain number which really never get over to the plate. This latter condition always holds true even though the plate potential is increased. Of course, the greater the value of the plate potential, the more electrons will be attracted.

An increase in plate potential will increase the plate current up to a certain point beyond which any further increase of plate potential will have no effect upon the plate current. This is the saturation point and depends upon the design characteristics of the tube. It is always true that a reduction of the plate potential will decrease the plate current as soon as the potential of the plate falls so low that the intensity of the electron stream from the filament to the plate is reduced.

In practice, it is desirable to maintain the filament temperature constant by adjusting the filament voltage to that recommended by the manufacturer and not to vary the plate current by varying the filament temperature. Plate current should be increased or decreased only by variation of the plate-supply potential, or the grid-bias voltage, as will be seen later.

3.3. Effect of Filament Current on Plate Current.—This effect was discussed in the preceding explanation, but in order that it may be clearly understood let us assume a practical example.

Suppose the plate is at a potential great enough so that it can attract 2,000 electrons per second from the filament. Suppose the filament is emitting 1,000 electrons per second. Each electron as it leaves the filament carries a negative charge, and, therefore, the space between the filament will be charged negatively to the value of 1,000 units, while the plate is charged positively to the value of 2,000 units. The result is that the plate charge is stronger than the filament space charge, and all of the electrons which leave the filament per second are attracted to, and reach, the plate.

Suppose, further, that the filament temperature is raised so that 1,500 electrons are emitted. The space charge is then 1,500 units negative and the plate, still remaining at 2,000 units positive, attracts nearly all of the electrons emitted by the filament.

Suppose now the filament temperature is raised so that 2,000 electrons are emitted making the space charge 2,000 units negative as against the plate charge of 2,000 units positive. The plate still attracts all of the 2,000 electrons emitted by the filament, but the saturation point for the plate potential has been reached; the space charge now equals the plate charge.

Up to this point there has been an increase in plate current for every increase in filament current because the path (the electron stream) between the filament and the plate has been increased. Now suppose that the filament temperature is increased so that 2,500 electrons are emitted. The space charge is 2,500 units negative as against the plate charge of 2,000 units positive. The result is that 500 electrons are repelled back to the filament; lost as far as their effect upon the plate current is concerned. Any further increase in filament temperature would be useless, as all the electrons over the 2,000 limit, which the plate will attract, are useless in effect. Therefore, increasing the filament current does not result in an increased plate current as long as the plate potential remains at the point where the plate attracts only 2,000 electrons.

If the plate voltage is increased, and the positive potential of the plate is raised so that more than 2,000 electrons are attracted to the plate, a still further increase in plate current will result. Thus, a constant increase in plate current will result until all of the electrons are attracted to the plate, or, in other words, until the saturation point has been reached. In general practice, however, the filament current is never

varied after the proper filament voltage has been applied. Hence, all changes in plate current must be made by a variation of the plate-supply voltage, and that only up to the point specified by the manufacturer. Tubes operated in excess of their designed plate- and filament-voltage ratings will operate inefficiently, and such operation may result in a considerable decrease of their normal operating life. A filament operating at a voltage of less than 10 per cent over its normal voltage rating may decrease to a value of 50 per cent of its normal operating period. The life of the various types of receiving and transmitting tubes is found to be between 1,500 and 5,000 hr., seldom more than 10,000 hr. It is good design practice, therefore, to provide a sufficient number of electrical indicating instruments (voltmeters, milliammeters, etc.) and fuses in vacuum-tube circuits, especially in transmitting circuits where operating conditions frequently change.

The preceding explanation should give the reader a fairly good idea of the relative effects of increasing the plate or filament potential, but he must not forget that the figures quoted were to make for simplicity of illustration only and that the electrons actually emitted may number in the millions. Furthermore, it should be born in mind that, even though the plate potential is at a point at which a maximum number of electrons are attracted (saturation), there are many electrons which never really reach the plate because of their tremendous repelling tendencies.

3.4. The Control Grid.—Bearing in mind that in the immediate vicinity of the filament there is a heavy negative field or space charge which is the true determinant of the amount of plate current that will flow when a positive potential is applied to the plate, let us see what would happen if a third element or grid is interposed between the filament and the plate.

The grid consists of very fine wires laterally arranged and spaced, so that a large portion of the electrons can pass through them. Now, just as the plate attracts electrons when it is positively charged, so will the grid attract electrons if a positive potential is applied to it.

Let us assume the grid to be connected to a variable potential, such as is illustrated in Fig. 3-4. It will be seen from this illustration that either a positive or negative potential may be applied by simply moving the sliding arm of the potentiometer (voltage-dividing resistance) either up or down from the center position. When the arm is in the central position, no e.m.f. is applied to the grid and, consequently, no effect is produced on the steady plate current as indicated by the plate milliammeter.

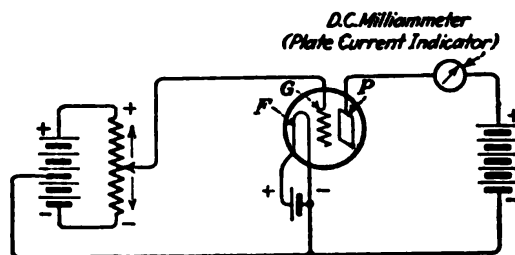


FIG. 3-4.—Circuit for providing variable bias to grid of vacuum tube.

Now let us assume that the slider arm is moved toward the extreme positive end of the resistance. A certain amount of positive potential will be applied to the grid depending upon the number of cells connected in series from the center tap of the batteries to the extreme positive (+) end. Assuming this to be three dry cells in series and each cell to have a voltage of 1.5 volts, the total positive voltage applied to the grid will be 4.5 volts. This voltage may be gradually decreased to zero by moving the sliding arm toward the center or zero point of the potentiometer.

Now, since it has been established that the positive potential of the plate will attract electrons, it is equally accurate that a grid interposed between the filament and the plate will also attract electrons when a positive potential is applied to it. However, owing to the fact that the grid is nearer to the filament than the plate, it will have a much greater effect on the electron flow than an equal charge on the plate. In other words, a positive grid in close proximity to the filament will cause a greater amount of electrons to flow toward the plate because of its tendency to "break up" or neutralize the heavy negative space charge present near the filament. If, on the other hand, the grid is made negative with respect to the cathode by sliding the movable arm toward the negative side of the resistance, the space charge will not only appear again but, in addition, will tend to repel electrons which otherwise would reach the plate, consequently reducing the plate-current flow below its normal value. Normal value is the amount of plate current flowing with zero potential on the grid.

The amount of increase and decrease of plate current in milliamperes depends upon the value of the positive or negative charges applied. In any event, however, no matter how feeble the amplitude of the positive or negative grid e.m.fs. applied to the grid, a relatively larger effect on the plate current will result. Consequently even very feeble signal impulses will produce relatively large plate-current variations. In this action lies the ability of the three-element vacuum tube to amplify feeble signal-voltage variations. Incoming radio signals are of an alternating character, and, consequently, they apply to the grid voltages of an alternating character.

3.5. Vacuum-tube Characteristics.—In order that the operation of a vacuum tube might be clearly understood when operating into load

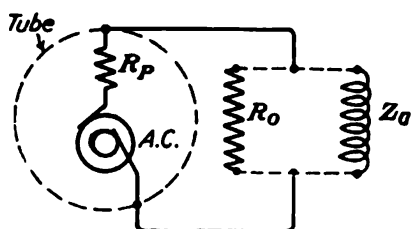


FIG. 3-5.—The vacuum tube and its load are analogous to an alternator and its load.

circuits, such as the primary windings of radio-frequency or audio-frequency transformers, the tube should be visualized as an alternating-current generator as illustrated in Fig. 3-5. Under these conditions a maximum power will be absorbed by the load resistance or impedance when the load is equal to the generator resistance or impedance. That is to say, if the load resistance R_o or impedance Z_o is matched to the generator impedance, the power transfer from one circuit into another circuit, such as from the primary winding to the secondary winding of a transformer, will be a maximum.

In vacuum-tube practice, however, these conditions are not always desired, particularly in alternating-current audio-frequency amplifying

circuits, owing to the fact that an exact matching of the impedance to the plate resistance may produce serious distortion of the audio frequencies. For this reason certain audio-frequency load circuits may have an impedance much greater or smaller than the tube (generator) impedance, depending upon the type of tube used. This is one of the most important fundamentals in engineering and it must be thoroughly understood to obtain a clear picture of vacuum-tube operation.

The electrical features and values of a vacuum tube are called its *characteristics* or *constants*. These are obtained by taking certain electrical measurements on the tube under so-called *static* and *dynamic* conditions.

Static characteristics are generally plotted in the form of curves, or they may be tabulated. The most general static characteristics to be presented in curve form are the I_p - E_p curves, obtained by varying plate voltage and measuring plate current for different values of grid bias. These curves are also known as *plate characteristic curves*.

Another form of static characteristics to be presented in curve form is the plate-current plate-voltage (I_p - E_c) curves, obtained by varying the control-grid bias and measuring the plate current for different plate voltages. These curves are also known as *transfer characteristic curves*. An example of this type of curve is shown in Fig. 4-26.

Dynamic characteristics are measurements made with an alternating voltage on the control-grid and with various values of direct-current potentials on the electrodes. The dynamic characteristics of a vacuum tube include the amplification factor of the tube, or its μ , its alternating-current plate resistance, R_p (equal to the alternating-current generator resistance in the analogy), and the *transconductance*, formerly called *mutual conductance*. The dynamic characteristics, used in conjunction with the load conditions, determine the operating characteristics of the tubes.

3.6. Amplification Factor.—The amplification factor μ depends primarily upon the distance between the plate and the grid and also upon the number of, and spacing between, the laterals constituting the grid, and the size of the grid wire. The greater the distance between the grid and the plate, the greater will be the amplification factor of a tube. This factor remains practically constant with a variation of the plate potential and may only decrease slightly at low plate voltages.

The *amplification factor* may be defined as *the ratio of a change in the plate voltage (necessary to give a change in plate current of a certain value) to a change of grid voltage (which will produce the same change in the plate current starting from the same initial conditions)*. Although the μ decreases somewhat at lower voltages, it is almost entirely dependent upon the geometry of the tube and is therefore a constant, called the *voltage amplification factor* or *constant* of the tube.

It is very easy to understand how this factor may be determined if the elementary function of the grid as a space-charge control is thoroughly understood. For example, when the filament is heated to the proper emitting temperature, the free electrons which are emitted find themselves under the influence of the electrostatic field created in the vicinity of the filament by the positive charge on the plate and the positive or negative charges on the grid. It will be remembered that the electron movement to the plate is a direct result of the charged fields set up by the plate and grid charges, respectively. Hence it may be seen that, through a variety of possible combinations of the plate and grid potentials, the number of electrons moving to the plate will be the same, regardless of what particular combination is used.

For example, if the plate potential is decreased causing a decrease in plate current, it will again be possible to restore the plate current to normal by making the grid potential more positive or less negative. Similarly, if the plate voltage E_p (symbol representing plate voltage) is increased or decreased by a small amount of dE_p (where dE_p represents a certain plate voltage change) causing a variation dI_p (where dI_p represents a change in plate current), the same plate-current variation may be obtained by keeping the voltage constant and varying, in the same direction, the grid voltage E_g (symbol representing grid voltage) by an amount dE_g , which will produce the same plate-current variation as did the plate-potential change dE_p . If I_p remains unchanged and all other electrode voltages are held constant,

$$\mu = \frac{dE_p}{dE_g} \quad (1)$$

Hence, to determine the amplification factor of a tube, apply a certain voltage to the plate of the tube, say 45 volts, and note the amount of plate current flowing at that potential. The grid potential during this operation must be zero. Now decrease the plate potential to about 35 volts and note the plate-current reading. Let us assume the plate current at 45 volts to be 2 milliamperes (ma.) and 1 ma. at 35 volts. This constitutes a decrease in plate current of 1 ma.; which is a difference of 1 ma. Hence, the amplification factor (μ) is equal to the change in plate voltage divided by the change in grid voltage. Thus, if a negative grid voltage produced the same decrease of 1 ma. as did the change of plate voltage from 45 to 35 volts, then, by noting the value of the grid voltage which produces this change, the amplification factor can readily be determined by the formula for μ .

Assuming the grid voltage which produced this change to be 2 volts negative, then, by application of the above formula the amplification factor will be found to be 5.

$$\frac{dE_p}{dE_g} = \frac{10}{2} \quad \text{or} \quad 5$$

Hence,

$$\mu = 5.0$$

3.7. Plate Resistance.—The plate resistance of a tube as usually specified in tube charts does not refer to the ordinary direct-current resistance between the plate and the filament but is the resistance offered to the flow of an alternating current (the signal variation) in the plate circuit. The plate resistance of a tube may be readily calculated from the values previously found for the amplification factor. If E_g is held unchanged, the formula for finding the plate resistance is as follows:

$$R_p = \frac{dE_p}{dI_p} \quad (2)$$

where dE_p = change in the plate voltage.

dI_p = change in the plate current.

Hence, in the previous example the change dE_p in the plate voltage was 10 volts, and the change dI_p in plate current 1 ma., or 0.001 amp. Thus, from the above formula the ratio of 10:0.001 will be found to be 10,000, which is the alternating-current plate resistance in ohms.

3.8. Transconductance.—One of the simplest methods for determining the amplifying efficiency of a vacuum tube is to compare the ratio of the amplification factor to the plate resistance of the tube. This is known as the *transconductance* or *mutual conductance* of the tube and is found by determining the effects of the interrelation between grid voltage, plate voltage, and plate current, which may be computed as

$$G_m = \frac{dI_p}{dE_g} \quad \text{or} \quad \frac{\mu}{R_p} \quad (3)$$

In other words, the transconductance of a tube may be defined as the ratio of a small change in the plate current to the change in control grid voltage necessary to produce this small change in the plate current, with all other voltages held unchanged.

3.9. The Alternating-current-operated Vacuum Tube.—The signal output of a vacuum tube is a result of the fluctuations in plate current producing changes in voltage across the plate-load impedance. If the plate and filament supply are obtained from batteries, the plate current with no signal excitation on the grid will be constant. If, on the other hand, the plate voltage is supplied by a rectifier system in which the alternating current is changed to direct current through the medium of rectifier tubes, a very efficient filtering system must be provided to smooth out the direct-current pulsations, or ripples. This may be effectively accomplished by using a filtering system as described in the sections on ripple filters (Chap. 6).

a. *The filament-type tube*, when operated from an alternating-current supply, requires that necessary provisions be made to maintain a steady potential between the filament and the plate. That is to say, the filament must be heated with an unvarying potential, so that the electron stream to the plate will be unaffected and steady. This condition might be obtained by heating the filament with a rectified and filtered alternating circuit. However, in view of the fact that the rectifier unit and filter coils would have to carry the filament currents it would necessitate the design of large current-carrying rectifier tubes and filter chokes. This procedure would not only make the cost prohibitive but impractical.

If, therefore, the filament is to be operated directly from an alternating-current supply source such as a transformer, means must be provided to minimize the effect of the alternating-current field upon the steady plate-current flow and the unsteadiness of the filament potential with respect to the plate.

For example, Fig. 3-6 illustrates a simple vacuum-tube plate circuit in which the plate voltage is assumed to be a well-filtered supply from a rectifier system which maintains a steady voltage upon the plate of the vacuum tube. The filament is lighted by an alternating potential from the transformer.

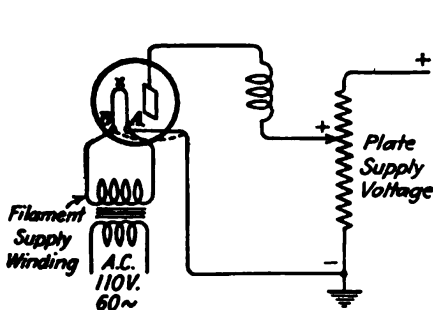


FIG. 3-6.—Illustrating effect of filament-return connection.

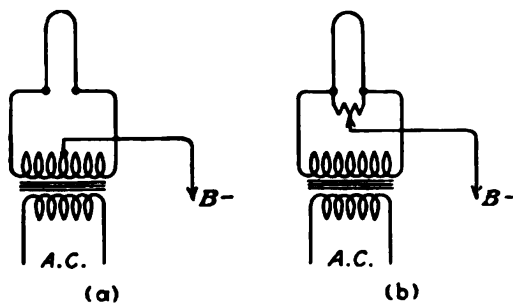


FIG. 3-7.—Two methods of connecting the filament-return to the filament.

Now, since the negative lead of the plate-supply system must be connected to the filament to complete the path of the plate-current flow, let us see what would happen if this lead is connected to the point A or B of the filament circuit. A plate-current flow would result in the form of an electron stream over to the plate, through the voltage divider and back to the filament, completing the circuit. However, since the filament potential at the points A and B is constantly reversing in polarity, due to the alternating potential of the transformer, the polarity of point A, to which the negative plate-supply lead is connected, is constantly changing. This produces a slight variation of the electron stream flowing to the plate of the tube at the frequency of the alternating-current reversals at the tube-filament terminals. Now, since this unbalanced condition produces a slight effect upon the plate-current flow, a moving magnetic field will be present around the transformer primary winding (shown here as a coil in the plate circuit), resulting in the inducing of an e.m.f. to the grid of the succeeding amplifier tube connected to the secondary of the transformer (not shown). The effect of this variation will then be amplified through the succeeding tubes and will finally be brought out through the audible reproducing system in the form of a hum.

Now, if the negative plate-supply lead is connected to some point of the filament circuit in which the potential is at all times zero, the electron stream to the plate would be unaltered, and a steady, or unvarying, magnetic field will result. Theoretically this condition could be accurately obtained if the negative plate-supply return lead were connected to the exact center of the filament at the point *X* (Fig. 3-6). This condition, however, remains true only if the paths from each side of the point *X* are equal in length. Otherwise the electrical balance would not prevail. Since it is not practical to bring the physical connection of the *B*— lead to the exact center of the filament, two satisfactory arrangements which will produce the same effects are illustrated in Fig. 3-7.

It is of great importance to have the *B*— lead connected to the exact electrical center of the filament to obtain perfect balance, and for this reason the resistance method illustrated in Fig. 3-7(*b*) is preferable. This method has a particular advantage in that the center tap may be varied to compensate for any unbalance due to a slight difference in the length of the connecting leads.

b. The cathode-heater tube is shown in Fig. 3-8, which illustrates the internal structure of the cathode-heater or equipotential tube. The

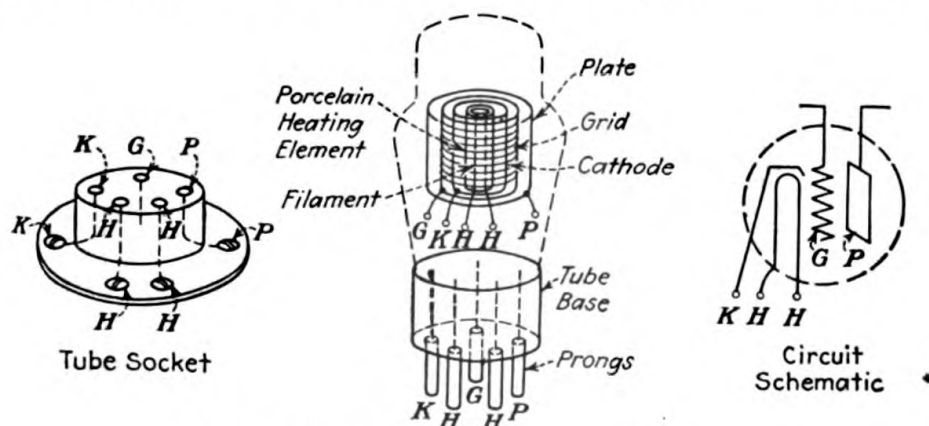


FIG. 3-8.—The heater-type vacuum tube.

filament or heating element is designated by *H H*, the cathode or emitter by *K* or *C*, and the grid and plate by the usual *G* and *P*, respectively. The heater unit or filament is, therefore, not used as an electron emitter, but serves only to supply the proper heat to the emitting element, the cathode. All of the elements are arranged in cylinders so that all points of the grid and plate are equidistant from the cathode, thereby allowing an equal flow of electrons in all directions.

If an alternating e.m.f. of the proper potential is applied to the heater terminals of the tube, the porcelain heating element will gradually become heated. This causes the cathode cylinder of nickel oxide to become heated sufficiently to emit electrons. In other words, the cathode cylinder and not the heater is the emitter of the electrons to the plate. Hence, if the negative lead of the plate-power supply system is connected to the cathode instead of the filament, the potential difference between the *K*

and P elements of the tube will be constant, even though the filament potential is varying at the alternating-current frequency.

The cathode-heater tube, therefore, will insure much less variation in the plate-current flow with alternating-current-operated filaments, thereby greatly reducing the possibility of an alternating-current hum.

There are, of course, other important factors which may contribute toward the elimination of an alternating-current hum in transmitters and receivers. For example, the filament wires carrying the alternating-current filament power must be twisted so that the magnetic fields between the wires will be canceled. Any varying magnetic fields situated near the grid or the plate wires may induce a sufficient alternating e.m.f. to produce an alternating-current hum.

When using the cathode-heater tube, the filament should also be center-tapped and grounded to eliminate stray capacity between the cathode and filaments. This is particularly important in transmitting circuits in which a slight potential difference existing between the filament and cathode may produce serious variations and modulations of the plate current. Perfect stability in all amplifying systems can only be obtained by the proper balancing and grounding of all filament and plate return circuits.

II. THE RADIO-FREQUENCY AMPLIFIER

3.10. General Amplifier Considerations.—The principles underlying the operation of audio- and radio-frequency amplifiers are the same, the only difference being that the frequencies to be amplified in the radio-

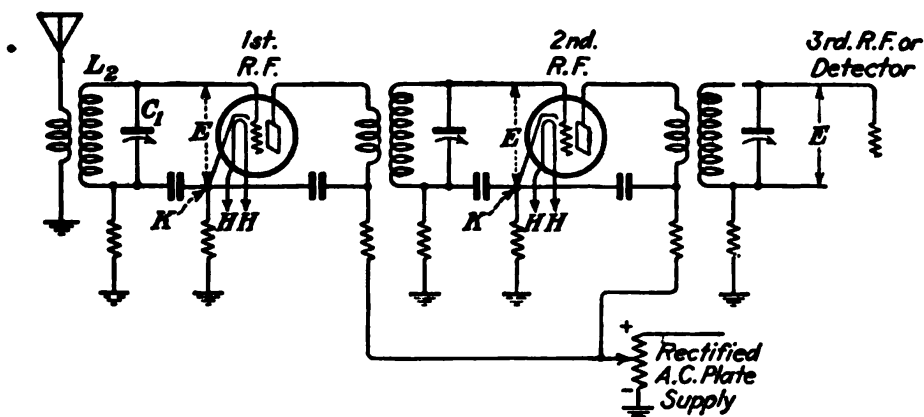


FIG. 3-9.—A typical two-stage radio-frequency amplifier (without neutralization) showing grid and plate filtering system.

frequency amplifier are considerably higher. Figure 3-9 illustrates a typical two-stage radio-frequency amplifier showing the grid and plate filtering system. Here the input voltages applied to the grid-cathode circuit of the first radio-frequency amplifier tube are obtained from the parallel-resonant circuit L_2C_1 .

When an incoming signal e.m.f. is induced in the secondary circuit L_2C_1 at resonance, a voltage is built up across this parallel combination. The value of this e.m.f. is dependent upon one or more of the following conditions:

- a. The step-up ratio of the radio-frequency transformer.
- b. The impedance of the parallel combination.
- c. The input impedance of the tube between the grid-filament capacity.
- d. The resistance of the L_2C_1 circuit.
- e. The reflected resistance or the mutual coupling M between the windings.
- f. The grid biasing voltage.
- g. The tuning of L_2C_1 .

It may be seen, therefore, that, if the number of turns in the radio-frequency transformer is larger in the secondary than in the primary, a greater e.m.f. will be applied across the secondary circuit at the points E .

If the impedance of the circuit L_2C_1 is kept large by maintaining a large L to C ratio, the e.m.f. across the parallel combination will also be considerably greater. That is to say, if the value of the capacity in the tuning condenser C_1 is kept as low as possible, and the value of L large, less current will circulate in the parallel-resonant circuit. Hence, the lower the current flow, the higher will be the effective impedance of the parallel circuit and the greater the voltage applied to the grid-filament circuit of the tube. This is an important consideration in the radio-frequency amplifier, particularly in receiving circuits, since the tube is to function primarily as a voltage amplifier. Thus, when very feeble signal voltages are being received, every available bit of e.m.f. must be secured to actuate properly the tube as a voltage-amplifying device.

The input impedance in a voltage-amplifying device must also be maintained as high as possible, particularly when small input voltages are being received. This is of great importance in the radio-frequency receiving amplifier because of the low signal voltages received.

The input impedance may be kept high by using a tube having a low grid-to-cathode capacity and by preventing a flow of grid current during the period in which signal voltages are being received. This latter condition may be fulfilled by maintaining the proper value of the negative C bias on the grid of the tube so that, when a positive potential is applied to the grid from the incoming signal, a minimum number of electrons will be attracted to the grid, thereby reducing the grid-current flow in the input circuit.

Now, if the maximum voltage E is built up across the grid-cathode circuit of the first radio-frequency tube, the voltage amplification A of the amplifier may be computed from the general expression

$$A = \frac{E_{o2}}{E} \quad (4)$$

In other words, the higher the μ of the tube the greater the amount of amplification or gain that may be expected in the plate or output circuit of the tube. This is, however, a rather general condition since certain other factors must be included to obtain a more accurate result.

Let us take, for example, the simple radio-frequency circuit in Fig. 3-10(a) and reduce it to an equivalent electrical circuit [Fig. 3-10(b)] containing a generator $E_p = \mu \times E_g$, a primary and secondary inductance L_1 and L_2 , respectively, with mutual inductance due to the magnetic coupling M , and the primary- and secondary-circuit resistances R_p and R_o , respectively. A variable condenser C is shunted across the secondary to tune the circuit to a small band of radio frequencies.

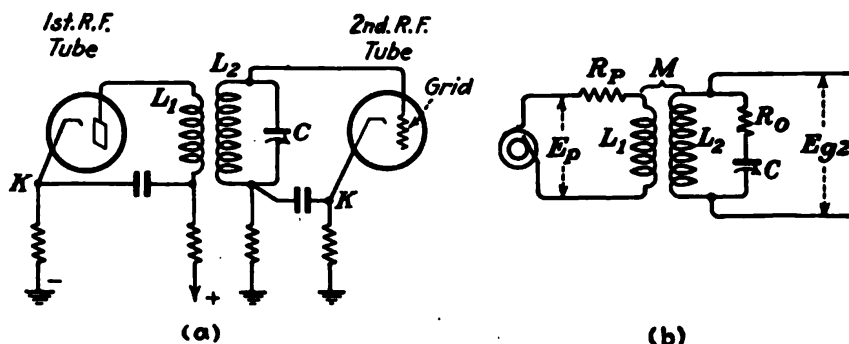


FIG. 3-10.—A simple radio-frequency amplifier circuit (a) and its equivalent (b).

The total voltage amplification or gain A of the tube and the transformer as a unit, therefore, must take into consideration all of the above factors. Hence, if it is assumed that the secondary circuit L_2C is adjusted to resonance, the total gain may be approximately computed from the ratio

$$E_{g2} = \frac{\mu E_g Z_o}{R_p + Z_o} \times \frac{L_2}{M} \quad (5)$$

where Z_o = load impedance.

It may be shown that, for each frequency to which L_2C is adjusted, there is some value of mutual inductance M which will give the best results. This of course depends upon the conditions required, namely, selectivity or fidelity.

If it is desired to obtain an extremely selective response so that the voltage amplification at some one frequency is sharply defined as illustrated in Fig. 3-11(a), then the value of coupling chosen should approach zero. That is to say M must be very small. If, on the other hand, fidelity is the important consideration, such as in broadcast receivers where the frequency-response curve must be wide enough to accommodate the modulated frequencies, the value of mutual inductance M must be so adjusted that the response curve approximates Fig. 3-11(b).

Hence, by decreasing the mutual inductance M between L_1 and L_2 , greater selectivity (sharpness of tuning) may be obtained, and, conversely, by increasing the mutual inductance M , a broader response may be obtained. Thus, it may readily be seen that receivers which require fidelity and sensitivity at the same time must have their coupling adjusted to obtain a mean mutual (*mutual inductance* is abbreviated to

mutual) which will satisfy both conditions. In other words, if a fixed mutual is used, as in the case of most radio receivers, the value of M must not be too small because, when the value of the tuning capacity C is decreased so that the circuit L_2C is tuned to a high frequency, the selectivity becomes so great that serious distortion will result. If the condenser capacity C is increased to decrease the resonant frequency of the circuit, the tuning will be slightly broader, but the sensitivity will also be much less. Thus, when the tuning becomes much sharper at the higher frequencies, the fidelity is seriously jeopardized and a compromise must be effected between the higher and

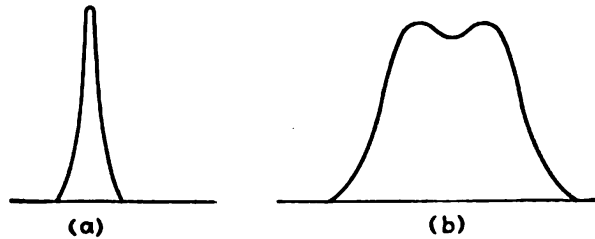


FIG. 3-11.—Frequency response curves.

lower frequencies to obtain the most desirable results. In other words, the amplification and fidelity should be uniform over the entire frequency band covered by L_2C (see Band-pass Filters, Sec. 5.20).

If, on the other hand, the mutual is too high (tight coupling), the resistance introduced into the secondary may be too high, which will result in a decrease in selectivity and possibly a decrease in amplification. This resistance may be computed from the ratio

$$R_o = \frac{M^2 \times (2\pi f)^2 \times R_p}{R_p^2 + (2\pi f L_1)^2} \quad (6)$$

A simple method of calculating the gain of a radio-frequency amplifier would be to determine the load impedance Z_o into which the tube is working, the amplification factor μ of the tube, and its plate resistance R_p . For example, let us assume a direct-coupled tuned load across the tube

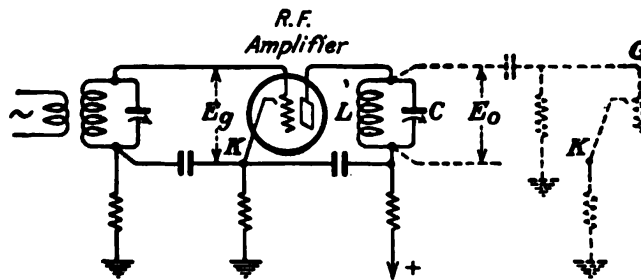


FIG. 3-12.—A direct-coupled tuned load across the output of a vacuum tube.

resistance R_p , as illustrated in Fig. 3-12, using a triode amplifier of the -27 type. The circuit LC is adjusted to the frequency to be amplified, say 1,500,000 cycles. Now if the value of LC , together with the resistance R in the coil, has an impedance Z_o of say 20,000 ohms at resonance, $Z_o = L/CR$, then the amplification or voltage gain may be computed simply by the product as follows:

$$E_o = \mu \times E_g \times \frac{Z_o}{R_p + Z_o} \quad (7)$$

As a practical example, let us take the 6J5 tube, which has a μ equal to 20 and a plate resistance of about 7,000 ohms. Assuming a load resistance of 20,000 ohms, we have

$$A = \frac{20 \times 20,000}{7,000 + 20,000} = \frac{400,000}{27,000} = 14.8$$

Thus the gain of this amplifier is approximately 15.

The voltage and power gain in radio-frequency and audio-frequency circuits is generally calculated in decibels, db, as explained in Sec. 10.6.

3.11. The Class A Amplifier.—In the general treatise on radio- and audio-frequency amplifiers just completed, all the tubes were operated

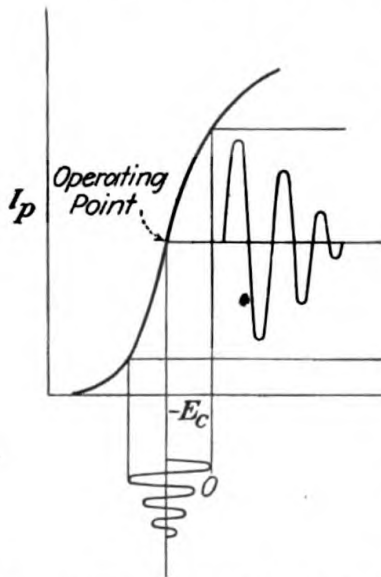


FIG. 3-13.—Class A amplifier operational curve.

at the straight portion of the I_p - E_c characteristic curve, so that the output-wave shape in the plate circuit is a linear reproduction of the signal-wave shape. This condition is clearly illustrated by the curve in Fig. 3-13.

All amplifiers operating on the straight portion of the curve are commonly known as *class A amplifiers*. Their efficiency is low, as is their output, while their ratio of power amplification is high (see Fig. 3-13).

Although the efficiency of a class A amplifier can not exceed 50 per cent, as can readily be seen from the general formula for computing amplifier efficiency, the fact that this type of amplifier will give a symmetrical reproduction of the input signal voltage makes it highly desirable.

$$\text{Amplifier efficiency} = \frac{100(E_p - E_{min})I_p}{2E_p I_{p(av)}} \text{ per cent} \quad (8)$$

where $I_{p(av)}$ = average value of plate current.

I_p = peak value of plate current.

E_p = normal value of plate voltage.

E_{min} = minimum voltage applied to the plate due to the drop across the plate load impedance.

Important: Proper operation requires that the tube be properly biased so that an incoming signal swing will not draw grid current during the positive halves of the cycle.

The class A amplifier should, therefore, always be used where the object is primarily voltage amplification and where power amplification is of secondary consideration. Radio-frequency and audio-frequency amplifier systems for receiving purposes generally use the class A method in all stages preceding the final power-amplifier stage. However, many

high-quality power-amplifier systems, particularly those used as speech amplifiers in broadcasting studios, use this system of operation in the final power-amplifier stage.

3.12. The Class AB Amplifier.—This class of amplifier is used only in push-pull audio-frequency amplification. Each tube is operated with a grid bias and excitation voltage so adjusted that the plate current in each tube flows for less than the entire excitation cycle, but for more than half the excitation cycle. From a practical standpoint the grid bias for class AB is placed about halfway between the class A adjustment and the cut-off point, the exact location depending on whether or not grid current is allowed to flow.

If grid current is not allowed to flow, this fact is signified by calling the amplifier class AB₁. If grid current is allowed to flow, the amplifier is called class AB₂. The employment of a grid bias permits the use of higher operating voltages on the class AB than on the class A amplifier. Also, because grid current flows in the class AB₂, this amplifier has a slightly higher output and efficiency than the class AB₁ amplifier.

The amount of distortion in the output of the class AB is somewhat greater than in class A but is not objectionable. The distortion with the class AB grid-bias adjustment is not so great as when the grid bias is adjusted to the cut-off point (class B). Hence, the class AB amplifier is more commonly used than either the class A or the class B audio amplifiers.

3.13. Class B and Class C Amplifiers.—The class B amplifier operates at the lower portion of the $I_p - E_c$ characteristic as illustrated in Fig. 3-14. When a signal e.m.f. is applied across the grid-filament circuit of a tube, the plate variations will resemble a half-wave output owing to the

adjustment of the grid bias to, or very nearly to, the point of plate-current cutoff. Hence, when an alternating e.m.f. is applied to the grid, the plate variations will take place only during the intervals in which the peaks of the signal or input voltage are positive. In other words, since no current is flowing in the plate circuit during the period in which no input voltage is applied, owing to the bias adjustment being at the blocking or cutoff point, no plate current can flow when a signal is being received during the negative halves of the cycle. This, of course, indicates quite definitely that the signal-wave shape is not faithfully reproduced in the plate circuit of the vacuum tube, owing to the loss of the

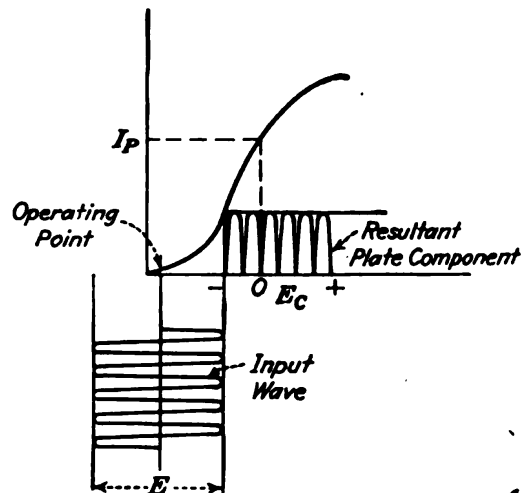


FIG. 3-14.—Class B amplifier operational curve. (Single tube)

negative half of the incoming cycle. In a radio-frequency amplifier, however, the full cycle may be reproduced in the plate circuit if an oscillatory or "tank" circuit is provided as illustrated in Fig. 3-15.

During the period in which the positive peaks of the incoming-signal alternating e.m.f. are applied to the grid of the tube, the potential difference across PF also applies an e.m.f. across the tank circuit CL since

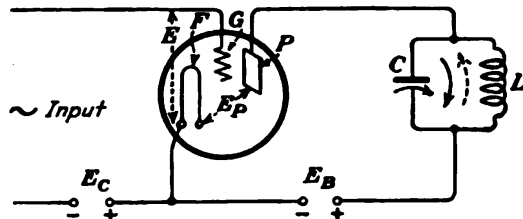


FIG. 3-15.—Tank circuit (LC) connected in plate circuit.

it is effectively in parallel to the tube generator PF . This charges the condenser C , which in turn discharges through the inductance L in the direction of the heavy arrow. That is to say, as soon as the positive peak in the plate circuit begins to diminish, the con-

denser discharges through L in the direction of the heavy arrow and discharges the condenser to the opposite plate. At this instant the positive peak in the plate circuit has disappeared owing to the reversal of the input grid e.m.f. to negative. During this negative period, no current flows in the plate circuit of the tube, and no e.m.f. is built up across PF . However, in view of the charge that has been built up on the opposite plates of the tank condenser, the circuit will continue to oscillate in the direction of the dotted arrow, thereby completing the other half of the wave lost by the negative signal cycle. This action is sometimes referred to as the inertia or *flywheel effect* of a tank circuit because the inductance and capacity resemble a mass in motion against the action of a spring.

Hence, the class B system may be successfully used in radio-frequency amplifiers by using a single tube without jeopardizing the wave shape in the plate circuit owing to the flywheel action of the tank circuit.

In audio-frequency amplifiers the class B system cannot be used with a single tube because no oscillatory or tank circuit is provided. Hence two tubes must be operated alternately to accommodate the complete cycle. This is known as a *push-pull* amplifier and is shown in Fig. 3-16. If this amplifier is so adjusted that it operates on the straight portion of the I_p-E_c characteristic curve, it is known as a class A push-pull amplifier. If the amplifier is adjusted so that it operates at or near the cutoff point, it is known as a class B push-pull amplifier.

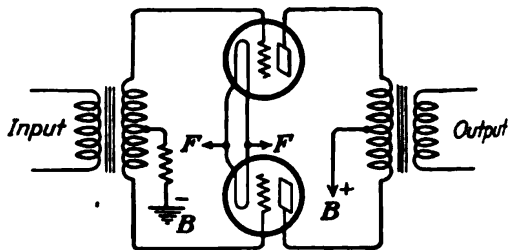


FIG. 3-16.—Push-pull method of connecting an audio amplifier.

When a tube is operating as a class B amplifier, the output power is proportional to the square of the grid-excitation voltage and consequently causes the output to resemble a linear characteristic. Class B amplifiers are, therefore, frequently classified as linear amplifiers. The linear output may readily be visualized by the graph illustration in Fig. 3-14. Class B amplifiers give medium efficiency and output, while their ratio of power amplification is low.

The class C amplifier is practically the same as the class B, with the exception that the negative grid-bias adjustment is beyond the cutoff point of the I_p-E_c characteristic curve, generally between one-and-one-half to four times the cutoff bias voltage.

The class C amplifiers must receive a considerably greater grid excitation to overcome the heavy negative bias if suitable plate-current peaks are to be produced in the output circuit. For this reason, and because a high order of harmonics is produced, class C amplifiers are used only in transmitting circuits.

The output of the class C amplifier varies essentially as the square of the plate voltage within limits. The ratio of power amplification for this class of amplifier is low, while the efficiency and output of the plate circuit are high.

3.14. Balance Circuits. *a. General Considerations.*—It will later be shown that a tube circuit may be set into oscillation if a suitable coupling is provided between the plate and grid circuit so that an e.m.f. may be developed across the grid and filament (input circuit) of the tube in question. This condition may develop either through an inductively or a capacitively reactive relationship, as in the Hartley and the tuned-plate tuned-grid oscillators, respectively.¹ The tube which is to function as an amplifier in either a transmitting or a receiving system *must under no circumstances develop sustained oscillations.*

If a receiving amplifier should go into self-oscillation, serious distortion and squealing would result owing to the effect of the oscillations "beating" against the incoming signal frequency. In addition the circuit tuning would become extremely sharp because of the decrease in the circuit losses introduced by self-oscillation. In other words, the circuit would be so selective that the band frequencies of telephone signals would be cut off so that only a narrow band of the modulated frequency would pass through, thus resulting in serious distortion.

If self-oscillation develops in a transmitting radio-frequency amplifier circuit where the plate voltages are considerably higher, the self-generated oscillations will seriously overload the tube, and the circuits to which it is connected, and may possibly ruin the tube by serious overheating. It may also burn out the radio-frequency choke coil, or the associated circuit resistances, or the plate milliammeter. When a power-amplifier tube goes into self-oscillation, the plate current in that circuit may increase to such large proportions that damage may result to the tube or circuit if they are not suitably protected with fuses or circuit breakers.

Great care must be exercised in neutralizing or balancing a radio-frequency amplifier not only to insure protection against overloading but also to obtain the maximum circuit stability.

¹ If the reader has no previous knowledge of the conditions which produce self-oscillation, it is recommended that he study Sec. 3.20 on General Oscillator Considerations before proceeding with this section.

All radio-frequency amplifiers using the triode tube must be neutralized owing to the internal grid-plate tube capacity which enables the energy to be fed back from the plate to the grid circuit. Tubes of the screen-grid variety do not generally require neutralizing because of their relatively smaller grid-plate tube capacity.

b. *The Hazeltine Balance.*—Figure 3-17(a) illustrates the fundamental principle of the well-known Hazeltine system of capacity neutralization, wherein the effect of the grid-to-plate capacity is balanced by means of an output transformer.

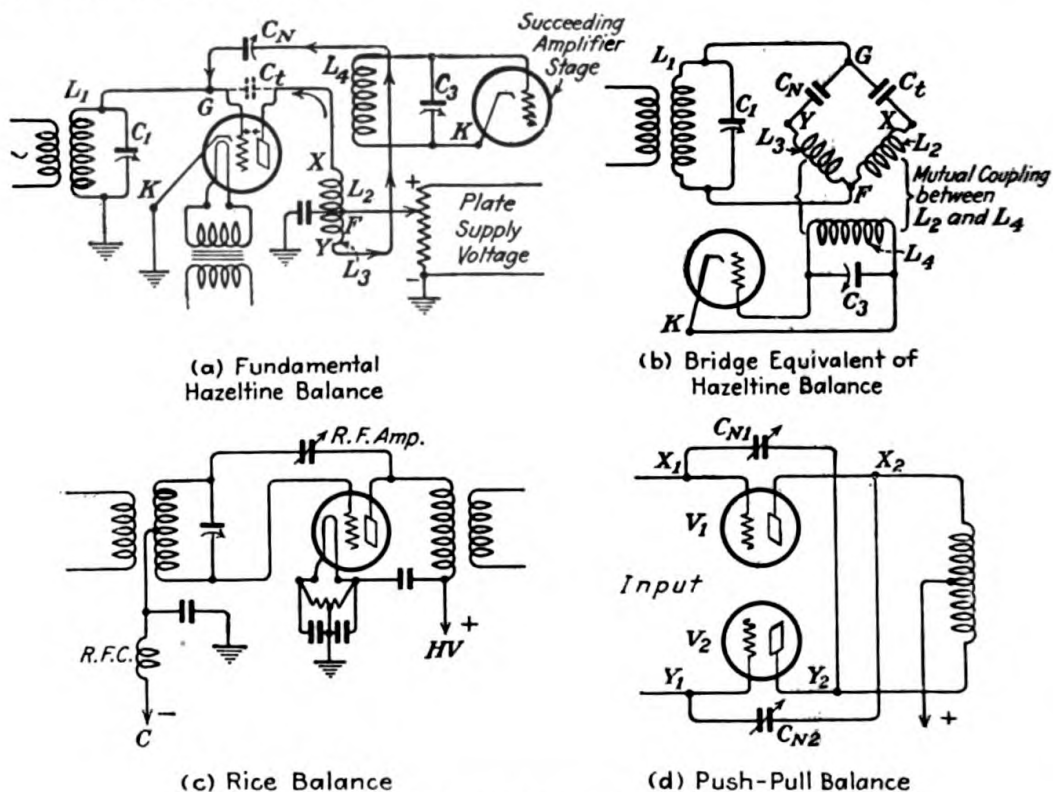


FIG. 3-17.—Balance or neutralizing circuits.

The units L_1C_1 represent a typical radio-frequency tuning system which may be adjusted to any frequency by the variation of L_1 or C_1 , usually the latter. Let us assume the condenser C_1 to be adjusted to its minimum capacity so that the inductance L_1 is the predominant frequency factor. It will be remembered that when the capacity across an inductance is increased the frequency of the circuit is decreased; or, in other words, the wave length increases with an increase of C across L . Since L_2 represents an untuned primary winding of a radio-frequency transformer, it can be seen that the physical period of this winding can be made to be at or near the physical period of inductance L_1 when the condenser C_1 is at a minimum capacity setting. Then the circuit is more apt to oscillate at this point than at any other owing to the resonant conditions existing between L_1 and L_2 . Consequently, any potential across

L_2 , when it is in resonance with L_1 , will induce an e.m.f. across L_1 through the tube capacitance C_i which may produce an oscillating condition.

It will be noted from the circuit diagram (Fig. 3-17a) that the direction of the feed-back e.m.f. will be from the plate to the grid through the grid-plate tube capacity. Hazeltine has shown that by the introduction of a third coil, or an equivalent arrangement, feedback to the grid from the plate may be overcome through the medium of an e.m.f. opposite and equal to that of the feed-back e.m.f. Referring to the circuit diagram (Fig. 3-17a), it will be seen that the high-potential ends of L_2 and L_3 are at the points X and Y , respectively. Thus, if the potentials X and Y are equal, by arranging them so that they oppose each other in the tube capacitance C_i , the feed-back effect from the plate to the grid will be canceled and the tube is said to be neutralized. This is done by connecting point Y to the grid through the condenser C_N which is called the *neutralizing condenser* and which serves to control the value of the opposing e.m.f. by virtue of its reactance.

The following explanation presents a more theoretical analysis of tube-capacity neutralization.

Figure 3-17(b) illustrates what is known as an alternating-current bridge-circuit arrangement and is equivalent in principle to the Hazeltine method of neutralization as applied to the circuit (a). The circuit illustrated differs from the conventional alternating-current bridge because of the magnetic coupling effect between L_2 and L_3 . That is to say, there is mutual coupling between the two arms of the bridge, and this value of mutual inductance due to the coupling must be added to the value of L_2 and L_3 . Furthermore, the inductive relationship of the secondary winding L_4 to L_2, L_3 must also be taken into consideration because it will affect their normal values. This condition of coupling reaction between the secondary and the two halves of the primary is usually taken care of by keeping the inductance of L_2 and L_3 nearly equal and using very tight coupling. This will cause the two circuits to affect each other equally.

Hence, if the bridge is properly balanced, the ratio is

$$\frac{C_N}{C_i} = \frac{L_2}{L_3} \quad (9)$$

This formula holds true provided the values of L_2 and L_3 include the mutual inductance of one another and also that of the secondary coil L_4 .

Consequently, if L_2 and L_3 have their turns wound in the proper directions, their respective magnetic fields will be in opposition, and, therefore, no e.m.fs. will be induced into the secondary circuit $C_s L_4$. In other words, no e.m.fs. will be developed between the points X and Y owing to the opposing currents flowing through L_2 and L_3 .

On the other hand, when a high-frequency current is flowing in the secondary circuit $L_4 C_s$, a varying magnetic field will be produced about L_4 which will produce a difference of potential (e.m.fs.) across the coils L_2 and L_3 . These e.m.fs. will be in opposition owing to the bucking effect of the windings on L_2 and L_3 and will, therefore, cancel out. This presumes, of course, that the capacity C_N is adjusted so that both arms of the bridge balance in respect to impedance value. This equivalent circuit (b) should be compared with the schematic diagram (a). The lettering on

both diagrams are equivalent for the points and circuit values indicated. When no current flows in either arm of the bridge, it is neutralized.

c. The Rice Balance.—Whereas the Hazeltine balance neutralizes the grid-to-plate capacity by the application to the grid of reverse e.m.fs. taken from the output transformer of the tube circuit, the Rice balance accomplishes the same purpose by energizing the neutralizing condenser from the input transformer. The scheme is illustrated in Fig. 3-17(c).

The Rice balance is very successfully used in many Western Electric transmitters employing single triodes as radio-frequency amplifiers.

d. The Push-pull Balance.—This system of neutralization is employed with push-pull radio-frequency amplifiers and is shown in Fig. 3-17(d). Assuming that the neutralizing condensers C_{N_1} and C_{N_2} are not present, it is seen that e.m.fs. of opposite polarities would be fed back to the grids of both tubes through the tube capacities. Assume that the plate of V_1 feeds back a positive (+) potential to its grid and V_2 feeds back a negative (−) potential to its grid. Now, if the neutralizing condensers are connected as shown, it is evident that the negative potential fed to the grid of V_1 from the plate of V_2 , through the neutralizing condenser C_{N_1} , will neutralize any equal positive (+) feedback to the grid of the same tube from its own plate. The same holds true for the other tube which is neutralized by energy fed from the plate of V_1 through the neutralizing condenser C_{N_2} . Thus the circuit is effectively neutralized.

3.15. Neutralization of a Transmitting Circuit.—In the neutralization of a transmitting radio-frequency amplifier circuit, some visible indicating method must be used in order to determine if the amplifier is properly balanced.

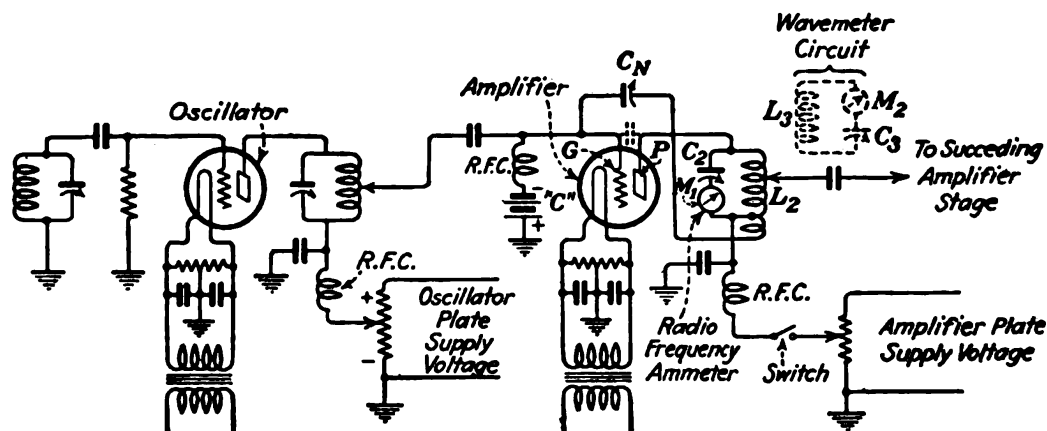


FIG. 3-18.—Illustrating methods of neutralizing radio-frequency amplifier in transmitting circuit.

Figure 3-18 illustrates a fundamental arrangement of a transmitting radio-frequency amplifier, showing the oscillator (driver) and the amplifier. Although a number of intermediate radio-frequency amplifiers may be used, only one stage is shown to illustrate the fundamental procedure which follows.

1. The plate-voltage-supply line on the amplifier stage must first be opened so that no potential whatever is applied to the tube. This is accomplished by opening the plate-supply switch.

2. The oscillator is then set into operation by closing the plate- and filament-supply circuits and setting the tuning adjustments to the desired operating frequency.

3. The oscillations generated by the driver tube are now applied across the grid and filament of the amplifier tube. Although this tube will not amplify the generated oscillations owing to the open plate-voltage circuit, a radio-frequency current of small amplitude will circulate in the oscillatory circuit L_2C_2 owing to the coupling of the internal tube capacity GP , if the neutralizing condenser C_N is at minimum capacity.

4. If no current indication is obtained on the radio-frequency ammeter M_1 , the circuit C_2L_2 may be improperly adjusted and the condenser C_2 should be varied. If there is still no indication, a more sensitive thermocouple radio-frequency ammeter must be inserted to record the small radio-frequency currents circulating in L_2C_2 at the resonant adjustment.

5. When an indication is obtained, vary the neutralizing condenser C_N until the oscillatory mesh current in L_2C_2 drops to minimum. The tube capacitance is now neutralized, and the plate-supply voltage may be applied to the amplifier tube by closing the plate-supply switch.

The same procedure may be duplicated through any number of radio-frequency amplifier stages, but all the circuits must be carefully retuned to insure the maximum resonant conditions between the circuits.

Another simple method for ascertaining the mesh currents in the radio-frequency stage to be neutralized is to place a standard wavemeter near the plate coil L_2 and adjust it to resonance with the driver frequency. When the circuit L_2C_2 is properly adjusted to this frequency the small mesh currents that flow in this circuit may be picked up by the wavemeter circuit L_3C_3 and indicated by the thermogalvanometer M_2 . The neutralizing condenser C_N may then be varied until this reading is reduced to zero, thus indicating that the circuit is neutralized. Care must be exercised not to bring the wavemeter too close to the mesh circuit, to prevent the possibility of damage to the sensitive thermogalvanometer M_2 .

This method cannot be used when the oscillatory mesh L_2C_2 is enclosed in a shielded compartment owing to the reduction of the exterior magnetic field around the compartment.

Balanced radio-frequency amplifiers, as illustrated in Fig. 3-17(d), are neutralized in exactly the same manner as for single tubes. It is important, however, that both of the neutralizing condensers have the same capacity and that all leads connected from the plate and grid circuits of both tubes are of the same lengths.

In high-quality transmitter design the two rotary plates of the neutralizing condensers are simultaneously operated by gears in order to obtain the exact capacity requirement and at the same time to make possible the neutralization of both tubes with a single control.

3.16. Radio-frequency Shielding.—The stability and interference-free operation of radio-frequency amplifiers in transmitting and receiving

depends primarily upon the neutralization of the tube capacity and the magnetic shielding of the associated tube and other circuits. If a radio-frequency amplifier is properly neutralized, self-oscillation may still occur if reactions take place between the grid and plate circuits owing to the magnetic coupling of coils or leads.

Figure 3-19 illustrates the arrangement of magnetic shielding in a radio-frequency amplifier circuit. The magnetic fields that are produced around the radio-frequency coils L_1L_2 and L_3L_4 , when an alternating signal e.m.f. is applied to the grid of the preceding tubes or exciting

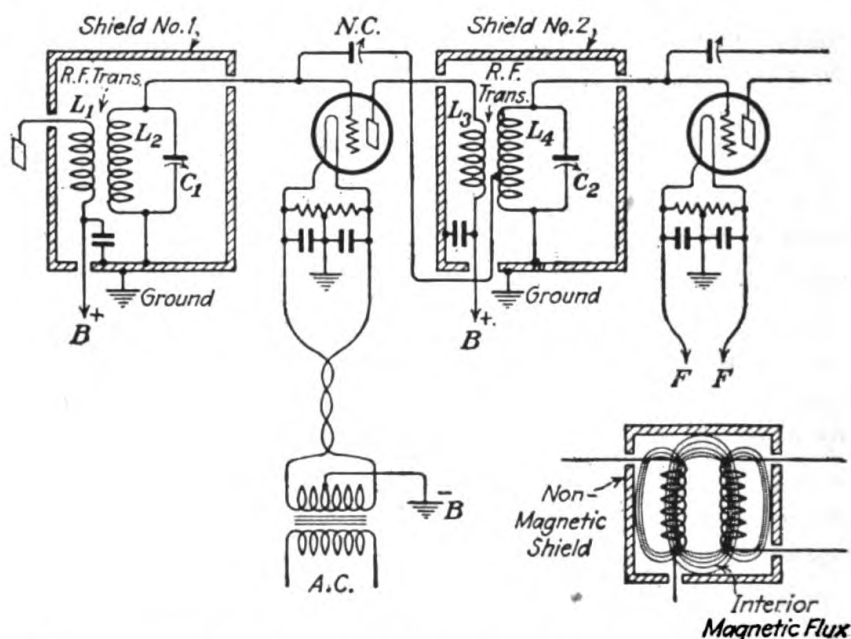


FIG. 3-19.—Illustrating effect of magnetic shielding on radio-frequency circuits.

circuit, are confined almost entirely to the enclosed compartments of the shields 1 and 2, as illustrated. The ability of the shielding to maintain the magnetic fields to the confines of the compartment depends upon the construction of the entire unit. This may be clearly seen if the theoretical functions of the circuit and shields are analyzed.

When a varying magnetic field is moving about the radio-frequency coils, the flux will tend to spread out in a more or less circular movement in which the distance of its travel depends upon the intensity of the currents flowing in the respective coil circuits. If, therefore, the fields are strong enough, and the two radio-frequency transformers are in the magnetic axis of each other, magnetic reactions will take place resulting in self-oscillation and instability. If, however, the coils are enclosed in a metallic compartment of non-magnetic material, such as copper, aluminum, or brass, and assuming that the compartment forms a complete electrical circuit, the varying magnetic fields around the coils will tend to displace electrons in the shield at the particular frequency in which the magnetic field is varying. This action generates small magnetic whirls, or eddy currents, which in turn produce their own magnetic fields and oppose the field created by the high-frequency currents circulating in the coils. This opposing effect varies directly with the frequency so that, as the frequency

increases, the shielding effect is greatly improved. In other words, if the shielding material is made of a high-conducting metal such as copper, and thoroughly closed to form a low-resistance circuit, the intensity of the magnetic field created by the eddy currents in the shield will oppose the coil fields and thereby reduce the external effect of the magnetic fields upon other coils or wires.

The efficiency of the shielding depends a great deal upon the high conductivity of the material used, because the greater the current that is flowing, the more effective will be the opposing or shielding effect. Great care must be exercised, therefore, that all ends of the compartment are thoroughly soldered to form a complete current path.

Shielding on Automobiles.—The fundamental methods of shielding, as outlined for aircraft in Sec. 9.9 on Aircraft Shielding and Bonding, apply equally well to the automobile. In addition, certain supplementary methods of noise suppression may be used on automobiles in instances where it is not practical to follow out the thorough methods which are standard practice for aircraft. Using these supplementary methods it is frequently possible to reduce interference to a minimum by the use of suppressors and filters and the proper arrangement of the antenna system.

This is accomplished by the use of suppressor resistances or radio-frequency choke coils and by-passing condensers. The use of a high value of resistance (approximately 25,000 ohms) in series with each of the high-tension wires leading to the spark plugs has been used with fair success. This method, however, is inefficient since it affects the efficiency of the engine performance by reducing the spark intensity due to the voltage drop across each resistance when the sparking current is passing through them. This defect may be overcome by the use of a larger ignition coil to compensate for the voltage drop. However, since the objective is to suppress the amplitude of the high-frequency surges passing through the high-tension wires by the introduction of a loss, the desired condition can be brought about much more efficiently by the use of a radio-frequency choke coil in series with each high-tension lead. A coil wound with No. 30 insulated wire with an inductance of approximately 5 mh. will have an impedance value to the high-frequency surges in excess of 25,000 ohms and yet will possess a very low direct-current value of resistance. With this arrangement, effective noise suppression will result without the usual drop in ignition voltage associated with the high-resistance method.

The following procedure is suggested:

1. With the engine stopped, install the suppressors on the spark plugs. Start the engine and, with the receiver turned on, observe the amount of interference.
2. With the engine stopped, install the suppressor in the center high-tension cable as close to the distributor as possible. Never install this or any other suppressor in the cable at the coil. Start the engine and, with the receiver turned on, observe the amount of interference.
3. A 1-mf. condenser connected across the commutator terminals of the generator will reduce noise suppression through the absorption of the commutator ripples and sparking. Similar condensers should be connected in the low-tension circuits, such

as in the light- and dashboard-wiring circuits, and across any device producing interference; these condensers to be placed between the ungrounded wires and the ground. These condensers serve as by-passing devices for radio-frequency surges picked up in the wiring circuits.

Considerable interference produced by the ignition system of the automobile is picked up by the antenna itself, particularly in that portion of the antenna leading from the radio receiver to the regularly built-in portion of the antenna on the roof top. If this lead is shielded up to the point where it enters the top horizontal portion, interference may be practically eliminated, provided of course that the shielded portion is thoroughly grounded. This method has a disadvantage in that the capacity relationship between the wire and shield serves to reduce the signal volume due to its by-passing or shunting effect across the input circuit of the radio receiver. The capacity effect may be reduced, however, by using a concentric tubing of wide diameter with the antenna stretched tightly through the center, thereby reducing the capacity relationship. This latter method would obviously have to be included in the initial body design to make it practical.

The United American Bosch Corporation recommends the following procedure for interference elimination:

The low-tension wires to the ignition coil or ignition switch should not be run in the same tube or conduit as the high-tension wires.

Reground the grounded side of the points directly to the motor block if possible. Oil and grease in the distributor often provide a poor ground, and, as a consequence, interference travels up the spark-control wire to the dash.

Make sure that the spark gaps are set in accordance with the engine manufacturers' specification, as contained in their instruction book.

Make sure that the terminals of the high-tension cables actually make contact with the wire itself. Small sparks originating at this point cause interference.

Make sure that the spark coil is well grounded. Varnish or enamel should be removed at this point. Old or cracked high-tension wire is a source of ignition noise and poor engine performance as well. Replace with a good grade of cable.

It is sometimes necessary to use shielded high-tension cables for the high-tension wire, running from the coil to the distributor. Avoid this, if possible. Ground the shielding carefully.

Separate the low- and high-tension wires at all points, particularly where they pass through the bulkhead.

Ground the motor blocks and bulkhead together.

Be sure that the hood is closed and latched when listening for ignition disturbance.

If it is necessary to insulate the metal terminals of the suppressors, use electrician's [rubber] tape. Ordinary friction tape is useless as an insulator of the high voltages used in high-tension ignition circuits.

Noise-suppression precautions in automobiles may be summarized as follows:

1. Complete magnetic shielding of all high- and low-tension cables and proper grounding.
2. Complete shielding of spark plugs and connecting wires and proper grounding.
3. Insertion of shielded radio-frequency choke coils or resistances in series with each spark-plug lead from the distributor.
4. Complete shielding of the spark coil unit and grounding.
5. By-passing of all low-tension wires to ground through a condenser.
6. Shielding of the vertical portion of the antenna leading to the receivers.

3.17. Inductance and Capacitive Changes with Shielding.—The inductance of a coil will decrease when enclosed in a non-magnetic shield owing to the reduction of the magnetic flux around the coil. This decrease in the inductance takes place because the magnetic fields set up by the eddy currents in the shield circuit are in opposition to the coil flux resulting in a total reduction of the lines of force. Hence, since the inductance of a coil depends upon the amount of energy that is stored up in magnetic form, any decrease in the number of the magnetic lines results effectively in a decrease of its inductance.

The electrostatic capacity, however, increases when a coil is placed in a non-magnetic shield owing to the relationship of the various parts of the coil to the shield. This condition is illustrated in Fig. 3-20. The capacity effect may greatly increase the effective resistance of the coil, particularly at high radio frequencies, since the condenser effect introduces additional energy dissipation or loss. The losses, due to shielding, may be considerably reduced, however, by using a shielded compartment of large dimensions so that the high-frequency resistance losses are minimized. Close-fitting shields must be avoided, if the maximum degree of efficiency (high Q) of a coil is to be obtained. The shield should be equidistant from all portions of the coil with a spacing of at least one-half of the diameter of the coil.

The shields must be thoroughly grounded to avoid a "floating" effect of the shield above the ground potential. That is to say, if the shielding is not connected to a ground, an electric field (a capacity) may exist between the shield and the ground owing to the potential difference between these two points. If, therefore, any wires or circuit parts are situated in this field, serious instability of the entire circuit may result owing to the effect of the field upon associated circuits. In some circuits, for example, particularly at very high radio frequencies, the connecting of two shielded compartments to the ground, as illustrated in Fig. 3-19, may produce considerable instability, particularly if the two compartments are separated some distance from each other. It would seem that if the two compartments were connected to the same ground on a metal chassis, no difference of potential would exist between these two points since they appear to be at the same potential. At very high frequencies, however, this is not true because the distance of several inches may introduce a voltage drop due to the resistance introduced at the high frequencies. In other words, the resistance between several inches in a metal chassis may be zero as far as low frequency or direct currents are concerned but may be fairly large at high frequencies.

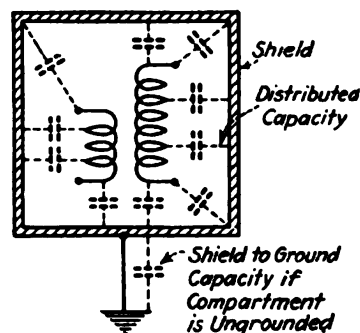


FIG. 3-20.—Capacity effects between coils and shielding.

At very high frequencies all common return leads must be connected to one point in as direct a manner as possible to reduce the voltage drops along the leads. If all leads are to be connected to a common chassis then a heavy strip of copper ribbon several inches wide should be used to reduce the voltage drops at the very high frequencies.

Great care must be taken that grid and plate leads are made as short as possible so that no magnetic or electrostatic fields may exist between these leads with preceding or succeeding radio-frequency stages. At extremely high radio frequencies, or in any high-gain amplifier, the grid and plate leads that extend outside of the shielding compartment should also be thoroughly shielded by a metal sheathing and grounded. Even the tubes themselves should be completely enclosed in a metal casing, particularly those of the high-gain screen-grid variety. Complete shielding of all high-frequency units is imperative if the maximum degree of efficiency and stability is to be obtained.

Low-frequency amplifiers and associated apparatus, such as audio-frequency transformers, power transformers, and choke coils, are generally shielded with magnetic materials to reduce the effect of the exterior flux upon near-by circuits. A magnetic shield of low reluctance provides a better path to the magnetic flux so that the exterior effect outside of the shielding is negligible. In effect, the magnetic shield acts as a short circuit to the flux path and thereby nullifies the magnetic field outside of the shielding.

3.18. Grid-biasing Methods.—It has been shown that the proper operation of all vacuum-tube circuits depends primarily upon the adjustment of the negative grid voltages or grid bias. Any one of many methods may be used to procure a definite value of grid bias. These are illustrated in Fig. 3-21.

Circuit (a) is the fundamental method of obtaining a C bias by the use of a cell or battery connected between the filament and the grid. The e.m.f. established across the cell terminals is applied directly across the grid and filament of the vacuum tube at the points E_c .

Circuit (b) is the same as circuit (a) with the exception that the negative C bias is supplied by a direct-current generator. This method is used only in transmitting circuits where high values of grid bias are required.

Circuit (c) is the most common system used in transmitting circuits where all-alternating-current operation is required. Here both the plate and grid-bias voltage supply is obtained from a rectifier and voltage-divider system. When using this method, great care must be exercised in filtering the plate and grid-bias supply, particularly the latter. If the grid-bias filtering permits the slightest variation in voltage so that a ripple is produced, the amplifying property of the grid will cause the ripple frequency to modulate the steady-flowing plate current resulting in serious distortion and hum. Typical plate and bias power-supply filtering methods are fully explained and illustrated in Chap. 6 on Rectifier Units.

In circuit (d) the grid bias is obtained as follows: When the filament is lighted and a steady direct-current potential is applied at E_p owing to the e.m.f. supplied by the

voltage divider (connected across the power supply), a steady electron flow from the filament to the plate will take place in the direction $FPRR_1F$. This constitutes the normal flow of plate current I_p , as indicated by the plate milliammeter.

Now, since the electrons flowing in the plate circuit must return to the filament to complete the circuit, any resistance connected between the negative terminal of the voltage divider and the filament will have an e.m.f. developed across it of a value $E = IR$. Thus, if the plate-current flow for some fixed value of plate potential is 20 ma., or 0.02 amp., and the value of the resistance R_1 is 2,000 ohms, an e.m.f. of 40 volts ($E = IR$) will be developed across the resistance. Hence, since the negative

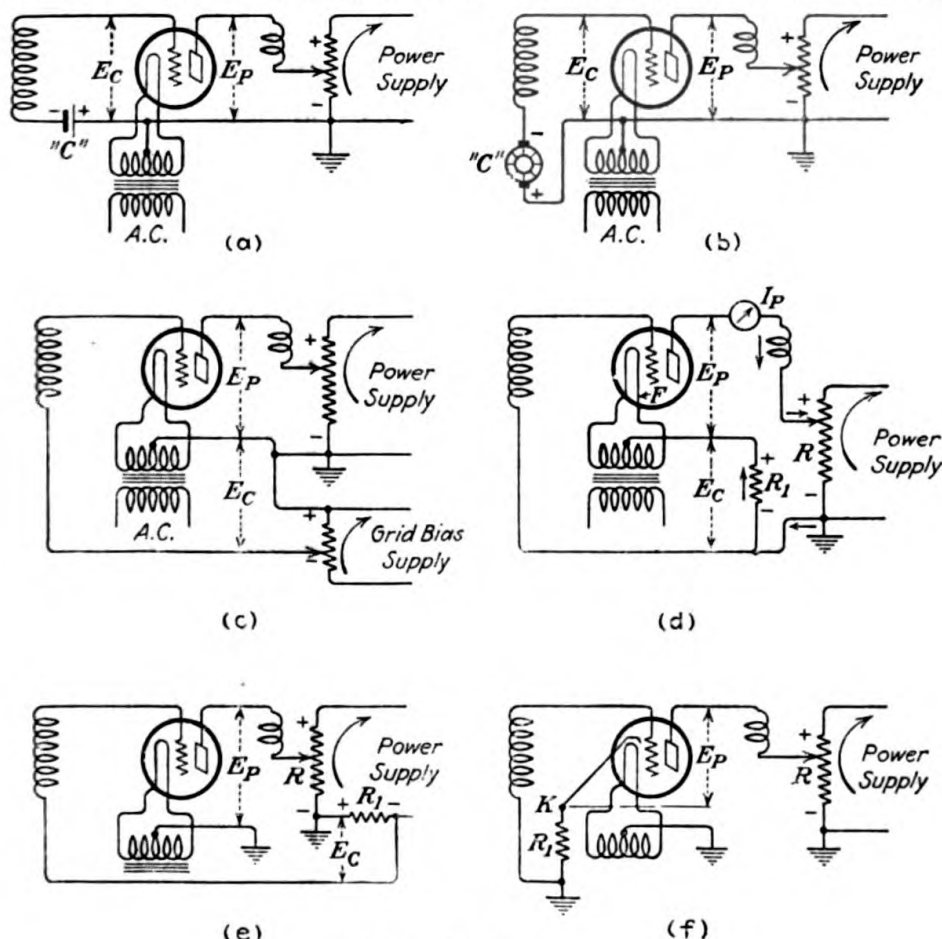


FIG. 3-21.—Methods of procuring grid bias.

end of the resistance is connected to the grid and the positive end to the filament, this voltage will be applied between the grid and the filament of the tube. In other words, the grid is 40 volts negative with respect to the filament owing to the voltage developed across the resistance.

Circuit (e) illustrates the same principle, with the exception that the biasing resistance R_1 is connected in the negative lead of the plate-supply system. Thus, the voltage developed across R_1 will depend upon the value of the resistance and the current flowing in the power-supply circuit. This is the common biasing method used in receiving circuits where the filament type of tube is used, such as in the final power-amplifier stage.

Circuit (f) is the biasing method used with the cathode-heater type of tubes. The operation is identical with that of circuit (d), with the exception that the biasing resistance is connected in series with the cathode instead of the filament.

When using the circuits shown in (d) and (e), the plate voltage is that of the power supply less the bias voltage. It is apparent, therefore, that to supply, for example, 180 volts to the plate and 33 volts negative bias, the power supply must provide 213 volts.

In actual practice all biasing resistances must be shunted by a condenser in order to provide a low-reactance path for the signal currents during the period in which the tube is receiving incoming signals. If a condenser is not provided, considerable signal energy will be dissipated in the biasing resistor. The proper arrangement of the biasing resistance and the by-pass condenser is shown in Fig. 3-9.

3.19. Radio-frequency Chokes.—*a.* The radio-frequency choke coil is an inductance used in transmitting and receiving circuits to keep the high frequencies out of the plate-power and grid-voltage supply circuits. The proper isolation of radio frequencies from supply circuits by the use of chokes and by-pass condensers also provides greater circuit efficiency, since the radio frequencies will be forced to take the path of lower reactance through the by-pass condenser connected ahead of the choke. Furthermore, the isolation of these radio frequencies from the supply circuits also prevents reaction between circuits which are connected to a common power-supply system thus insuring a maximum degree of circuit stability. Circuits which do not provide proper isolation because of choke coils or resistors in the grid and plate circuits and receive their power supply from the same source react with each other owing to what is generally known as *common impedance coupling*.

When choke coils are not used it is also possible to prevent reactions due to this coupling by the use of grid- and plate-filter resistances as previously explained. The disadvantage of the resistance-isolation method particularly in high-current-carrying circuits is the IR drop produced across the resistances. Although this method is highly efficient and generally used in low-current-carrying circuits such as in receivers, the choke-coil method is preferred where a high-impedance isolation is required with a minimum of direct-current resistance or IR drop.

The design of the choke coil, however, to perform efficiently as a high-impedance reactor is relatively a much more difficult problem since the distributed capacity reactance X_c between the turns in the winding may provide a low-reactance path around the high coil reactance X_L . That is to say, the frequencies instead of being impeded may be actually by-passed through the capacity of the coil thus making the isolation desired ineffective.

Figure 3-22(a) and (b) illustrates the most common arrangement of radio-frequency choke coils (R.F.C.) in the plate and grid circuits. Diagram (c) represents the theoretical circuit which may be analyzed as follows.

During the period in which no e.m.f. E_s is developed, a steady plate current will flow through the circuit in the direction of the straight arrows. This flow will be unaffected by the impedances Z_o and Z_c since it is assumed that a well-filtered direct current has been developed at the power-supply source. Small IR drops may take place across these impedances, however, owing to the direct-current resistance present in the coil windings, but these are negligible.

Now let us assume an incoming signal to be developed in the equivalent plate circuit of Fig. 3-22(c), and that it is desired to keep the plate-current variation

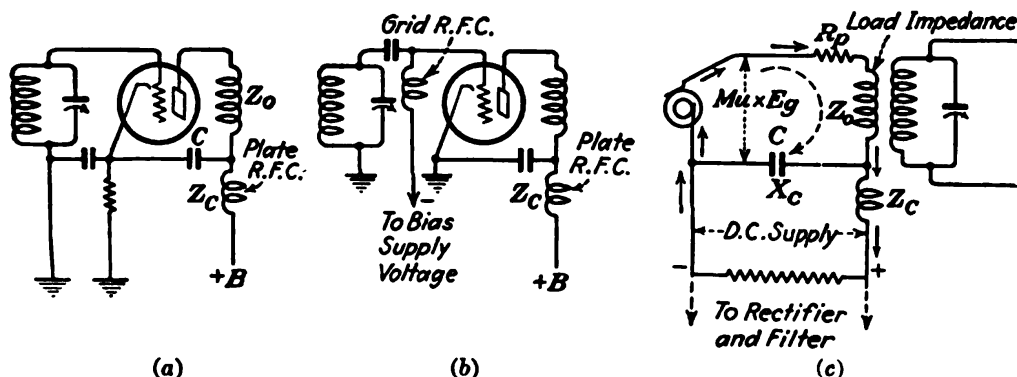


FIG. 3-22.—Common methods of connecting choke coils in plate and grid circuits.

due to this signal (called the *alternating-current plate component*) out of the direct-current supply circuit. In order to accomplish this, the alternating-current plate-current component must be provided with a low-reactance path Z_oC in the direction of the dotted arrow. By the application of alternating-current engineering principles it will be seen that the total signal current flowing through Z_oC will be dependent upon the ratio of the impedance of the choke coil Z_c to the by-pass reactance of C , thus:

$$\text{By-passing efficiency} = \frac{Z_c}{X_c} \quad \text{or} \quad \frac{R}{X_c} \quad (10)$$

Now let us assume that the lowest radio frequency to be developed in the plate circuit through $Z_oC = 500,000$ cycles. The value of the capacity and choke coil should be so designed that the impedance to the lowest frequency through C is extremely low, while the impedance through Z_c is very high. If the choke coil has a value of 100 mh. and a direct-current resistance of 200 ohms, then the impedance to a frequency of 500,000 cycles will be 314,000 ohms.

The ratio of current flowing through the condenser C will be Z_c/X_c . Hence, if it is desired to increase the percentage of the high-frequency component flowing through Z_oC , it will merely be necessary to increase the ratio to the point in which the ratio approximates 100. When this has been accomplished, the reactance of Z_c will be considered sufficiently high to isolate the frequencies from the power-supply circuit. Hence, if the impedance value of Z_c is very high, a smaller capacity may be used at C . This is a theoretically desirable condition since, if the value of C is kept small, condensers with mica dielectrics may be used, thereby insuring a minimum dielectric loss. Small-capacity condensers will also have less inductive effect—a condition which is generally present in larger capacities and highly undesirable in radio-frequency circuits. Unfortunately, however, it is extremely difficult to increase the inductance of the choke coil without introducing too much distributed capacity and reducing the effective impedance. Even though the inductance may have a high reactive value theoretically, the distributed capacity shunted across it will greatly reduce its effective impedance, particularly at the higher frequencies. The efficiency of the choke coil, therefore, depends greatly upon its design, and in highly efficient

circuits the choke generally consists of several spaced "pie" sections, wound on an efficient insulation form, connected in series to reduce the distributed capacity and to reduce dielectric absorption and losses. The size of wire used will depend upon the heat-carrying capacity of the winding, particularly in the plate filtering circuits of vacuum-tube transmitters where the plate currents may be considerable.

b. Choke-coil and Plate-filter Design.—If the ratio of the impedance Z_c to the reactance X_c [Fig. 3-22(c)] is nearly 100, the current flow through C will be a maximum. Practically, if this ratio is even as low as 60, the percentage of plate-current flow through C will be very close to maximum. As the ratio falls below 60, however, the percentage of flow through C decreases relatively more rapidly. A value of capacity should be used in which the ratio is equal to at least 60. Assume the value of C to be 0.5 mf. and the frequency 500 kilocycles, giving an X_c of 0.6 ohms. Now, if a radio-frequency choke of 20 μ h is inserted at Z_c it will have a reactance of approximately 63 ohms at a frequency of 500,000 cycles. Then the ratio of

$$\frac{Z_c}{X_c} = \frac{63}{0.6} = 105$$

This would indicate, in accordance with the above explanation, that the ratio is sufficient to pass through C a maximum value of the alternating-current plate-current flow. This would be true if the reactance due to Z_c were pure inductance containing absolutely no distributed capacity, but since this is practically impossible the value of Z_c must be made considerably larger to introduce sufficient impedance to overcome the inherent distributed capacity. Roughly the value of the choke impedance Z_c for radio-frequency circuits should be about 4,000 times greater than the ratio indicated, or $20 \mu\text{h} \times 4,000 = 80 \text{ mh}$. No hard and fast rules can be applied to an accurate calculation of radio-frequency chokes owing to the many variables introduced by distributed capacity, high-frequency resistance, and design. Although it is possible to obtain a relatively greater degree of accuracy by the use of resistances in place of choke coils, these, too, present difficulties due to their IR -drop losses, inductance, and distributed capacities, particularly at the higher radio frequencies.

In low-frequency amplifiers, where resistances are used in place of Z_c , this ratio is highly accurate since the distributed capacity is a negligible quantity at these frequencies. Hence, if the circuit in Fig. 3-22(c) is a low-frequency amplifier circuit in which Z_c is the primary winding of an audio-frequency transformer and Z_c is replaced by a resistance R , and if C is a low-frequency by-pass condenser, then the values of C and R may be readily computed by the ratio R/X_c . For example, if the ratio of 100 is assumed and a frequency of 50 cycles is applied, then the values of R and C to effect efficient by-passing and isolation from the power-supply circuits must be 300,000 ohms and 1 mf., respectively. Owing to the fact, however, that there is very little difference in the filtering efficiency between a ratio of 100 or 50 in audio-frequency systems, the latter is preferable since it will permit the use of a lower plate-filter resistance and thereby reduce the IR drop across the resistance to the plate of the tube. Thus, at a frequency of 50 cycles, a plate-filter resistance of 150,000 ohms may be used, since $R/X_c = 150,000/3,000 = 50$. The values of R and C are always calculated on the basis of the lowest frequencies that are to be amplified, since the reactance of C decreases with an increase of frequency.

If lower resistances are desired to effect lower IR drops, the value of C may be increased proportionately to produce the same result. In this case a condenser value of 10 mf. having a reactance of 300 ohms at 50 cycles and a plate-filtering resistance of 15,000 ohms would produce the same result.

In receiving circuits the resistance method of radio-frequency filtering is advisable because in the low-current-carrying circuits the IR drop is negligible. The resistances used for this purpose should be of the non-inductive type.

III. VACUUM-TUBE OSCILLATORS

3.20. General Oscillator Considerations.—A vacuum-tube oscillator consists essentially of an oscillatory circuit [generally a parallel-resonant circuit, Fig. 3-24(b)], a vacuum-tube amplifier, and a feed-back circuit. In the oscillatory, or output, circuit, electrical oscillations occur according to the fundamental laws governing this type of operation. The feed-back circuit takes a part of the energy from the output circuit and impresses it in the form of a voltage on the grid and filament (the input circuit) of the vacuum tube, where it is amplified and again returned by the plate-filament circuit to the output circuit, supplying the losses occurring in the latter and thus keeping it oscillating. The feed-back circuit may consist of capacitive coupling through the grid-plate capacity of the tube, or inductive coupling through a coil in the grid circuit magnetically coupled to the output circuit. Thus, the vacuum tube itself does not oscillate but merely amplifies the electrical impulses impressed on its grid from the oscillatory circuit and delivers this amplified energy back to the output circuit to make up for the losses therein, in order to maintain its oscillations.

3.21. Fundamental Oscillator.—The fundamental circuit in Fig. 3-23(a) shows a simple vacuum-tube oscillator capable of producing waves

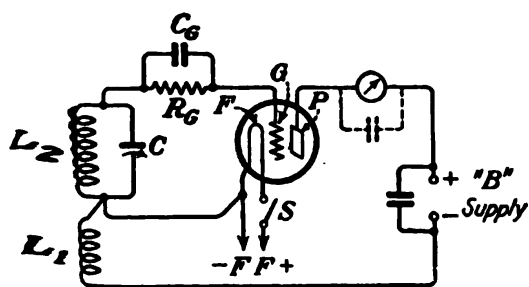


FIG. 3-23a.—Fundamental oscillator circuit.

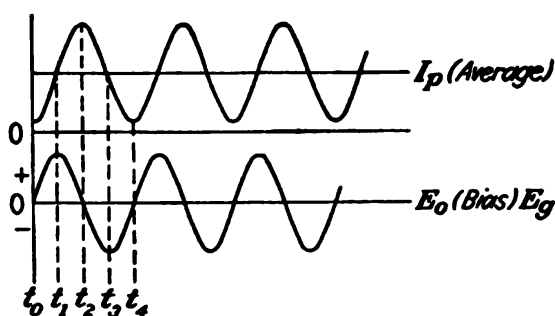


FIG. 3-23b.—Curves illustrating oscillator action.

of a continuous character. The theoretical functioning of this circuit is identical to almost every form of tube transmitting-circuit oscillator and should be carefully analyzed.

The moment the filament switch S is closed and direct current applied, the filament emits electrons which bombard the plate. This electron flow from the filament to the plate will constitute a flow of current in the plate circuit, beginning at time t_0 (Fig. 3-23b); which current will flow through the coil L_1 , resulting in the building up of a magnetic field around this coil. This expanding magnetic field will cut coil L_2 , inducing in it a voltage. The polarities must be such that this induced voltage applies a positive potential to the grid, causing increased plate current.

The voltage on the grid is proportional to the rate of change of plate current. When the plate current has reached a certain critical value (at time t_1 on the figure), its rate of change will decrease owing to the current limitations of the tube. As the

rate of change decreases, the grid voltage also decreases, causing the rate of change to decrease still farther. Thus when the plate current reaches a maximum (at time t_2 on the figure), the rate of its change is zero and the induced voltage on the grid coil is also zero.

As the plate current starts to decrease, the rate of its change becomes negative with respect to the beginning of the alternation. Thus a negative voltage is induced on the grid and the plate current is decreased farther. This action continues until the plate current reaches minimum (at time t_4 on the figure), at which time the rate of change is zero and the grid voltage is also zero.

One cycle of oscillation has now been completed. The action just described repeats itself as long as the circuit is closed and operating voltages are applied. Hence, continuous oscillations are generated.

In all forms of oscillating systems, especially those in which the frequencies are high, precaution must be taken to keep the resistances of the constants low. Otherwise the oscillations are apt to stop, and difficulty might be encountered in bringing about consistent transmission. These losses; especially at the higher frequencies, are due to various conditions such as high-frequency resistance losses, dielectric absorption caused by poor insulating materials, eddy currents, poor connections, and other loss-producing conditions.

3.22. The Hartley Oscillator.—Figure 3-24 illustrates the circuit arrangement of the well-known Hartley oscillator. The principles of oscillation are the same as in the fundamental oscillator described in the preceding section. The series-feed arrangement in diagram (a) is in fact theoretically identical with that of the fundamental oscillator.

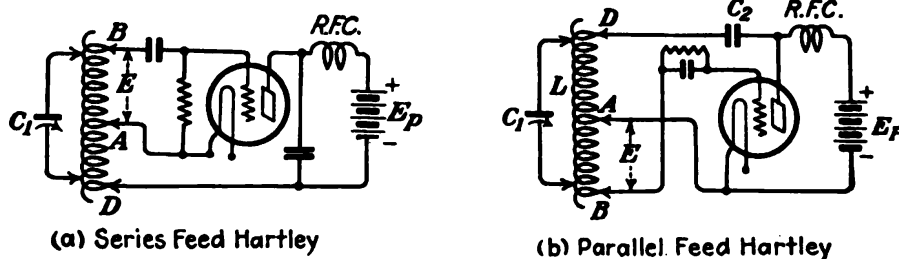


FIG. 3-24.—Hartley oscillator circuits.

The grid excitation takes place across the grid coil and the points A and B owing to the reactance drop X_L of the coil. The proper value of this reactance will depend upon the type of tube used and the grid-excitation voltage required. The grid excitation in both the series- and the parallel-feed arrangements takes place through the medium of the induced e.m.f. from the plate portion AD of the coil to the grid portion AB with the exception that in the *parallel feed* (b) the initial excitation takes place through the plate-blocking condenser C_2 in the form of a dielectric displacement of electrons. This displacement causes a movement of electrons in the plate coil which produces a magnetic field. This condenser also serves to block out the direct-current component of plate-current flow from the oscillatory circuit thereby allowing only the high-

frequency currents to flow in the L and C circuits. This condenser must have a low reactance (X_c) to the operating frequencies to minimize the drop across it, so that it may deliver the proper potential across the plate-excitation coil. This condenser must, however, have a sufficiently strong dielectric to withstand the constant direct-current and oscillating potentials across it. The grid leak makes the oscillator self-starting and self-biasing.

3.23. The Colpitts Oscillator.—Figure 3-25 illustrates the circuit arrangement of the Colpitts capacitive feed-back oscillator.

The theoretical operation of this circuit is identical with that of the Hartley parallel-feed system with the exception that the grid-excitation voltage appears across the capacitive reactance C_3 . The initial excitation is produced as before through the plate-blocking condenser C_2 in the form of an electron displacement which in turn also produces a displacement in the plate-excitation condenser C_1 . This results in a potential difference across C_1 and C_3 which excites the grid and produces sustained oscillations.

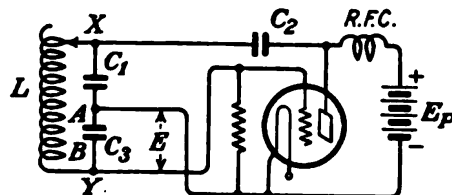


FIG. 3-25.—Colpitts oscillator circuit.

The frequency of these oscillations will depend upon the oscillatory circuit constants L and C , thus,

$$f = \frac{1}{2\pi \sqrt{LC}} \quad [\text{Chap. 2, Eqs. (59) to (61)}]$$

The total reactive voltage present across the two condensers at the point XY may be divided by the proper choice of the plate- and grid-excitation condensers C_1 and C_3 so that the correct voltage drop across C_3 may be obtained for proper grid excitation. The higher the reactance X_c of the grid-excitation condenser, the greater the potential difference or e.m.f. across it. In practice the ratio of C_3 to C_1 is usually about 3 to 1.

3.24. The Push-pull Oscillator.—The theoretical operation of the push-pull oscillator is identical with that of the push-pull or balanced amplifier to be explained in a later section, with the exception that the grid voltages are developed in the circuit itself, as in any form of oscillator, through a medium of inductive or capacitive feed-back reaction.

A typical circuit arrangement of a push-pull oscillator is illustrated in Fig. 3-26(a). The instantaneous operation of the tube V_1 in diagram (b) now to be explained is through the circuit shown by the solid lines. At the instant of any instability in the plate or filament circuit, such as would be caused by closing the power-supply circuit, a potential difference E_p is developed across the plate-excitation coil L_1 . During the period in which the instability took place a momentary moving of the magnetic field was developed across L_1 . In accordance with the laws of induction,

therefore, an e.m.f. E_g will be developed across L_2 . This in turn excites the grid G of V_1 . Since C and L_1 represent a tuned circuit connected across the tube, the circuit will be set into self-oscillation at a frequency depending upon the L - C constants of the circuits. After the initial impact to the oscillatory circuit has occurred, sustained oscillation will take place resulting in an excitation of both grids, 180 degrees out of phase with each other. By the proper adjustment of the two grid connections to the inductance, perfect symmetry or balance may be obtained.

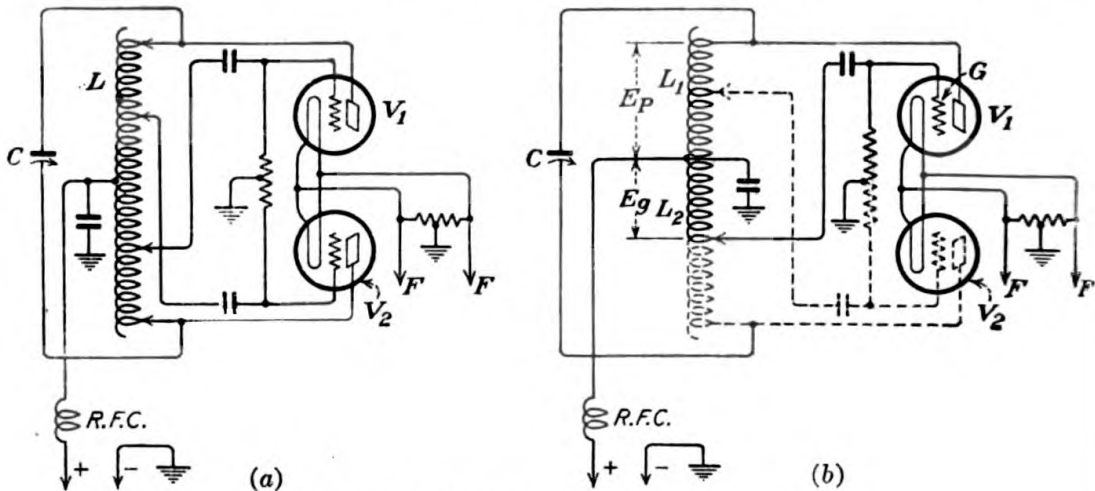


FIG. 3-26.—Balanced or push-pull oscillator circuit.

The advantage derived from an arrangement of this kind is greater power output and better frequency stability owing to the reduction of the tube input and output capacity, since, with this arrangement, both tubes are effectively in series across the tuned-load circuit. This gradually reduces the circuit losses caused by tube capacity and makes this form of oscillation highly desirable for use at high radio frequencies where large power-oscillation outputs are required with good frequency stability.

3.25. Conventional Electron-coupled Oscillator.¹—Figure 3-27 illustrates an electron-coupled oscillator which may be used in all radio-frequency circuits in which an oscillator is required. This circuit is particularly adaptable to receiving systems employing the superheterodyne principle.

The frequency of the oscillations generated is determined by the oscillatory circuit $L_1C_1C_2$ as in all other forms of oscillators. The circuit differs, however, from the conventional oscillator in that no capacitive, inductive, or direct coupling exists between the load and grid circuits. Although it is apparent that oscillations may be generated without

¹ The following articles are also recommended to the reader desiring full information on the development of this circuit:

Dow, Electron-coupled Oscillator Circuits, *QST*, January, 1932;

Dow, A Recent Development in Vacuum Tube Oscillator Circuits, *Proc. I.R.E.*, December, 1931.

inductive coupling through the medium of the internal grid-plate tube capacity, such as in the tuned-plate, tuned-grid, and crystal-controlled oscillator, these conditions do not occur in the electron-coupled type of oscillator.

In the electron-coupled oscillator the inter-electrode grid-plate capacity is either neutralized, or the plate is shielded by the use of a third screen grid. In the latter method, the addition of a third grid near the plate acts as an electrostatic screen, thus making neutralizing unnecessary. Hence, if no capacitance is present between the plate and the control grid G_1 , and no other electrostatic or magnetic relationship exists between

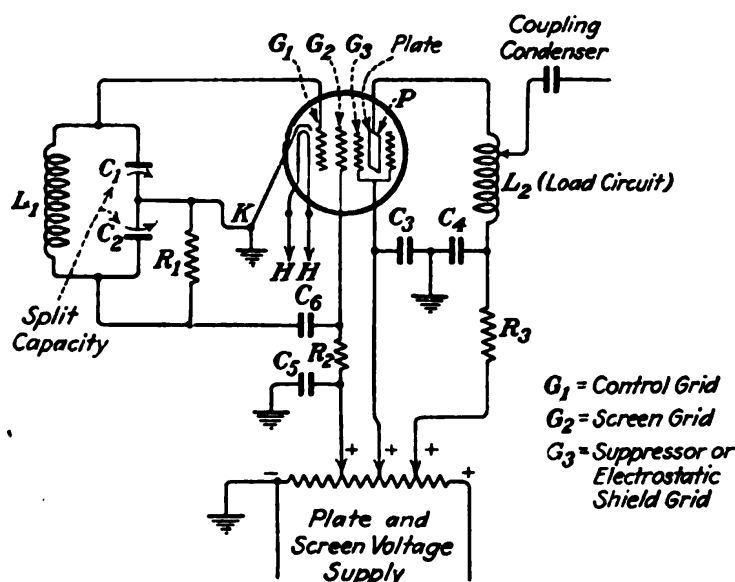


FIG. 3-27. — Electron-coupled oscillator circuit using pentode tube explained in Sec. 5.3.

the plate and grid circuits, any oscillations that are generated in the frequency-controlling circuit L_1, C_1, C_2 can affect only the load circuit through the medium of the electron flow between the cathode K and the plate P . Hence, the variations in the plate circuit, because of the electron pulses transmitted to the plate from the cathode, generate in the plate circuit a pulsating direct-current variation at the frequency of the generating circuit L_1, C_1 . This in turn produces an alternating e.m.f. in the plate circuit at a frequency determined by the pulses of electrons impinging on the plate.

Hence, since there are no reactions taking place between the load and frequency-generating circuits owing to electrostatic or magnetic coupling, and because the coupling is due solely to the electron stream to the plate, the names *electron-coupling* or *electron-coupled oscillator* are generally applied.

The exceptional frequency stability which may be obtained with this circuit owing to the negligible effect of the load-circuit variations upon the

frequency-controlling circuit makes this form of oscillator desirable for low-power oscillating systems.

It can be seen that the cathode and grids G_1 and G_2 together form a Colpitts oscillator circuit with the screen grid G_2 acting as a plate. The frequency of oscillation is then determined by the resonant frequency of L and C .

The condensers C_3, C_4, C_5 , and C_6 are radio-frequency by-passes to maintain a low-reactance path for the alternating-current variations in the load and screen circuits. The combination of C_6 and the resistance R_1 serves to apply a negative bias to the control grid to insure a maximum degree of stability during the period in which the circuit is oscillating. The resistances R_2 and R_3 are isolating units to keep the radio frequencies out of the power-supply circuits, thereby additionally insuring circuit stability. These may be in the form of either non-inductive resistances or choke coils.

The load circuit in an electron-coupled oscillator may be either reactive or resistive so that L_2 may be satisfactorily replaced with a resistance. The power developed in the load circuit will of course be dependent upon the relationship of the load unit to the alternating-current plate resistance, R_p , of the tube, as in all impedance-matching circuits.

3.26. The Dynatron Oscillator.—Figure 3-28 shows the circuit arrangement of a screen-grid tube used as a dynatron oscillator.

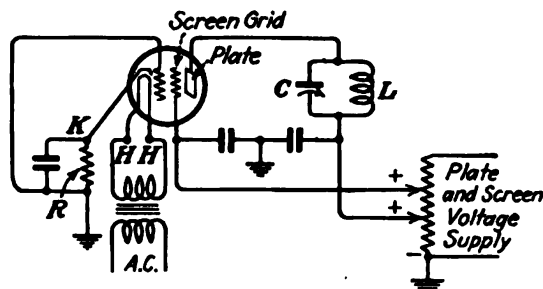


FIG. 3-28.—Dynatron oscillator circuit using screen-grid tube explained in Sec. 5.2.

The dynatron oscillator presents a characteristic called *negative resistance*¹ which is well known in the theory of regeneration and which may also be used for other purposes requiring similar characteristics.

The theoretical operation of the dynatron oscillator may be described briefly as follows:

When the filament is lighted to incandescence and a plate potential is applied between the plate and the filament, an electron flow from the filament to the plate will result in accordance with the elementary theory of vacuum-tube operation.

If the grid is operated at a higher positive potential than the plate, the electrons arriving at the grid will cause an electron flow in the grid circuit of fairly large amplitude, which is, of course, true in conventional circuits when large signal potentials

¹ See Regenerative Detector, Sec. 5.23.

are applied to the grid. The important function, however, remains in the electrons that have passed through the grid laterals toward the plate. These electrons on arriving at the plate cause a breakdown of the surface tension, owing to the collision impacts, which results in an emission of electrons from the plate surface. This phenomenon is known as *secondary emission*. Now, since the grid is at a higher potential than the plate, the electrons due to secondary emission will be attracted to the grid. This presents a condition in which both the electrons from the filament and from the plate (the latter due to secondary emission) will be attracted to the grid. Now let us assume the plate voltage to be gradually increased. In ordinary tube circuits an increase in plate voltage would result in an increase in the plate current, but in this circuit the gradual increase in plate voltage reduces the plate-to-filament current flow owing to the neutralizing effect at some critical point between the normal electron emission from the filament circuit and the secondary electron emission from the plate. When this particular point is reached, the plate-to-filament circuit resistance would indicate a negative resistance characteristic if an alternating-current potential were applied to the circuit. It is this peculiarity which is the basis of the action of a dynatron oscillator.

Note on Tuned-plate, Tuned-grid Oscillator: This type of circuit is identical with the crystal-controlled oscillator explained in the next chapter, except that the grid-circuit load consists of an inductance and capacity which form the grid parallel-resonant oscillatory circuit.

IV. RADIO AND POWER-CIRCUIT COMPONENTS

3.27. Radio Circuit Components.—Some of the more common radio circuit components are shown in the chart, Fig. 3-29. A detailed explanation of each part follows. (Item number preceding name of device corresponds to illustration number on chart, Fig. 3-29.)

1. **ADJUSTABLE WIRE-WOUND RESISTOR.**—This type of resistor is designed to handle relatively heavy power. It is wound with a high-resistance alloy wire on a porcelain or other ceramic core. It is used particularly as a bleeder resistance or voltage divider on electronic power-supply units and for general experimental work. These resistors are generally available in sizes from 10 to 200 watts for full resistance. The wattage that may be safely dissipated at fractional settings is proportional to the effective length of the section used. Thus a 200-watt resistor will dissipate 100 watts over half of its winding. The resistance range of the unit shown is 1 to 10,000 ohms.

2. **FLAT-TYPE WIRE-WOUND RESISTOR.**—This type is generally available in $2\frac{1}{2}$ -watt fixed or variable units with a resistance range from 1 to 3,000 ohms. It is also available as a non-inductive fixed-value resistor with a power-rating range of 10 to 100 watts and a resistance range of 10 to 10,000 ohms. The flat-type resistor is designed for general use.

3. **CHARGING RESISTOR.**—Designed for use in battery-charging circuits and wound to dissipate maximum heat, this type is usually available in 50-, 75-, and 100-watt ratings.

4. **ANTENNA INSULATOR.**—The unit shown is made of porcelain with smooth white glazing; available in lengths of 7, 12, and 20 in. with break strength of 800 lb.

5. **CARBON PRECISION RESISTOR.**—This is an extremely stable unit, particularly recommended for high-resistance voltmeter multipliers and for photoelectric and other circuits requiring high dependability as it is accurate to 5 per cent. It is available in $\frac{1}{4}$ - and 1-watt sizes. Typical dimensions are $1\frac{1}{4}$ by $\frac{3}{8}$ in.

6. **WIRE-WOUND PORCELAIN-CORE RESISTOR.**—The distinctive feature of this resistor is its small size, being not over 2 in. in length on a $\frac{3}{16}$ -in. core. Usually available in 10- and 20-watt sizes, with a resistance range of 1 to 100,000 ohms, it is used mostly in receivers.

7. **LOW-POWER RADIO-FREQUENCY PLATE CHOKE.**—This choke consists of a continuous universal winding in four sections wound on a ceramic low-loss core. Typical value is $2\frac{1}{2}$ mh.; distributed capacity, 1 mmf.; direct-current resistance, 50 ohms; current rating, 125 ma. It is used for low-powered transmitters and all types of receivers.

8. **POWER RHEOSTAT.**—This device is a type of variable resistor suitable for power uses such as motor-speed control, field rheostat, and charging resistor. The resistance wire is wound toroidally on a base of porcelain or other refractory material. It is available in sizes from 25 to 300 watts, these ratings being based on continuous operation in free air with a temperature rise not exceeding 300°C. Typical diameter for a 50-watt rating is $2\frac{1}{4}$ in.

9. **MICA CONDENSERS.**—These units are available in sizes ranging from 0.000025 to 0.06 mf. The working voltage may be from 300 to 1,000 volts in the low-voltage range and from 1,000 to 10,000 volts in the high-voltage range. These condensers are used as by-pass condensers and as lumped capacities in transmitting circuits. A typical approximate size is $1\frac{1}{4}$ by $1\frac{3}{4}$ by $\frac{5}{16}$ in.

10. **TUBULAR PAPER CONDENSERS.**—These condensers are used in low-voltage circuits not greater than 1,000 volts working voltage. They are non-inductively wound and sealed in wax-impregnated-paper tubes, with ends filled with sealing wax to protect the condensers against moisture. Typical dimensions for the 0.006-mf. size are $1\frac{3}{8}$ by $\frac{1}{2}$ in. They are available in sizes ranging from 0.0001 to 1.0 mf.

11. **HIGH-FREQUENCY SOLENOID CHOKES.**—These units are designed to function as radio-frequency plate chokes and are built to carry up to 1,000 ma. The winding is a single-layer solenoid on a steatite core, insulated and protected by a moisture-proof coating. The choke can be designed to avoid fundamental or harmonic resonance on the working frequency band. It varies in size from $1\frac{3}{4}$ by $\frac{1}{4}$ in. for $2\frac{1}{2}$ -meter use to $6\frac{1}{2}$ by $\frac{3}{4}$ in. for wave lengths up to about 250 meters.

12. **POWER TRANSFORMERS.**—These units are made in a great variety of types and sizes to function as filament- and plate-supply units. High-quality units are built with low-loss high-permeability silicon-steel cores. The coils are wax impregnated under high compression to give long life under continuous service. Units are available to supply one or two filament-voltage values in addition to the plate power. A typical size is 3 by $4\frac{1}{2}$ by $3\frac{3}{4}$ in. to supply 700 volts for plate-power and filament-voltage values of 6.3 C.T. and 5.0 volts.

13. **COIL FORM.**—This is the type of insulating core support on which are wound coils for receivers and low-power transmitters. It is fitted with from four to six prong contacts for insertion into standard sockets. Typical size for receiving sets is $1\frac{1}{4}$ in. in diameter by $2\frac{1}{4}$ in. high, and for transmitting sets $2\frac{1}{4}$ in. in diameter by $3\frac{1}{2}$ in. high.

14. **TRANSMITTING-TUBE SOCKET.**—This is designed with ceramic base and heavy brass- or nickel-plated shell. The unit shown is the standard 50-watt size with double heavy-current filament contacts and contacts for grid and plate, a total of four terminals being provided. Types without the shell are also available.

15. **TRANSMITTING INDUCTORS.**—These are designed for use as grid and plate inductance in transmitting circuits. Some types are fitted with banana-type plugs so that various sizes of coils may be used as desired. These inductors can be designed to handle any practical power.

16. **FILAMENT OR AUDIO TRANSFORMERS, FILTER CHOKE, AUTOTRANSFORMER.**—The outward appearance of these four devices may be similar.

RADIO AND POWER CIRCUIT COMPONENTS

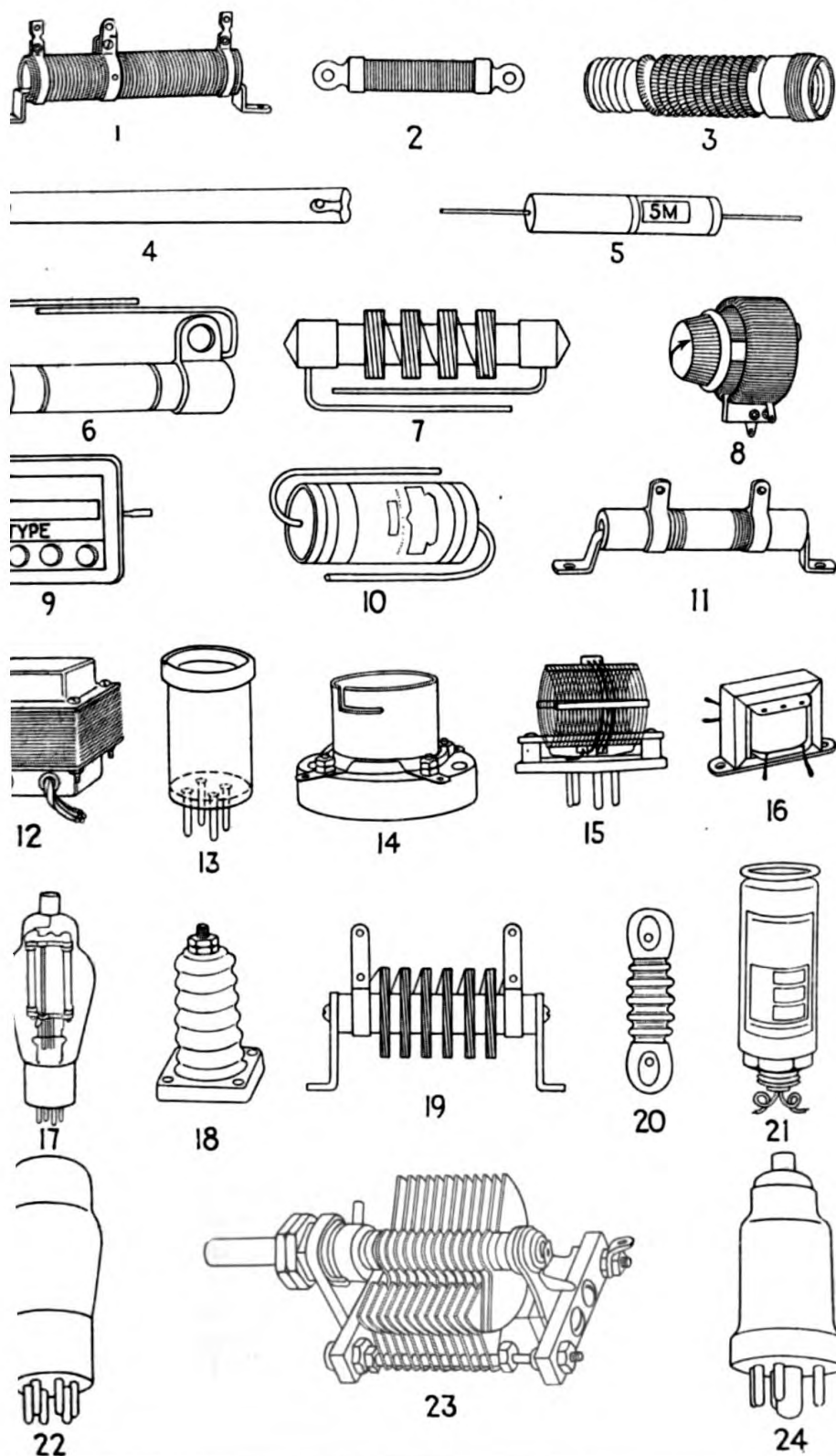


FIG. 3-29.

a. *Filament transformer* is usually designed for a minimum heat rise, and ratings are for continuous operation at full load.

b. *Audio, or interstage, transformers* are used for coupling the plate or plates of an amplifier stage to the grid or grids of the next stage.

c. *Filter chokes* for audio- and power-frequency circuits are designed as smoothing chokes for rectifier filters and as ripple-filter chokes for use with direct-current-generator plate-power units. As such, these chokes are used in conjunction with filter condensers to form the complete filter unit.

d. *Autotransformer* is a one-winding transformer so connected that a certain portion of the turns is common to both the primary and secondary circuits. The method of connection is similar to a potentiometer connection. (See *T*, Fig. 12-11.)

The conventional transformer with primary and secondary windings may be connected to operate as an autotransformer. The method of connection can be visualized by considering the primary terminals to be numbered 1 and 2, and the secondary terminals 3 and 4. Then, to connect as an autotransformer, terminals 2 and 3 are joined; the input voltage is impressed across terminals 1 and 4; the load is connected across terminals 3 and 4.

The advantage of the autotransformer over the conventional induction transformer is that the autotransformer is more efficient if the ratio of transformation is not too large. The autotransformer requires less copper and iron for a given power capacity than does the induction transformer. Also, the losses in the autotransformer are less, which accounts for its higher efficiency, and its regulation is very much better than that of the induction transformer.

17. **TRANSMITTING TUBE.**—The tube shown is an air-cooled medium-power type with a rating of 225 watts (RCA 811) and is used singly in low-power transmitter circuits or in multiple in high-power circuits.

18. **STAND-OFF INSULATOR.**—These units are usually made of white glazed porcelain, Alsimag, or steatite, in heights from approximately 1 to $4\frac{1}{2}$ in. They are used to support high-frequency, high-voltage conductors associated with radio installations.

19. **PIE-TYPE RADIO-FREQUENCY CHOKE.**—This type of winding is used on chokes designed for the higher currents up to 1,500 ma. A typical choke of this type is rated as follows: equivalent impedance of more than 500,000 ohms; wound with six pie windings on an Isolantite core, inductance rating of 2.5 mh., distributed capacity less than 1.5 mmf., direct-current resistance of 8 ohms, capacity to carry safely maximum direct-current (continuous) of 500 ma., intermittent operation permitting higher current, overall size, less brackets, of $1\frac{3}{16}$ by $2\frac{1}{2}$ in.

20. **STRAIN INSULATOR.**—These units are usually made of glass, porcelain, or steatite and are available in lengths from 3 to 12 in. They are especially useful in breaking up guy wires into short sections to prevent them from acting as parasitic radiators.

21. **ELECTROLYTIC CONDENSER.**—These units are available in both wet and dry types, as explained in Chap. 6 (see Index). They are usually supplied in hermetically sealed aluminum cans. The type shown is designed to screw into a holding base. Other types are supplied with tab terminals or wire leads. A typical full-size can measures $1\frac{3}{8}$ by $3\frac{1}{2}$ in. The trend in wet electrolytic condensers is toward smaller sizes. A typical midget size is 1 by $3\frac{1}{4}$ in.

22. **GLASS-TYPE VACUUM TUBE.**—This is the conventional vacuum tube used in millions of home radio receivers. Multigrid types may have contact on top of the tube for control grid, as shown on the transmitting tube, item 17.

23. **VARIABLE AIR CONDENSER.**—This type of condenser consists of two sets of plates, a stationary set and a movable set, the latter being commonly referred to as the rotary plates. The capacitance of the condenser is maximum when the plates com-

pletely overlap and may be decreased by a withdrawal of the rotary plates from intermeshing with the stationary plates. Variable air condensers are used in receiving and transmitting circuits in maximum capacitance values ranging from 50 to 500 mmf. The total number of plates may vary from 3 to 45 as usually manufactured. Because the dielectric is air, the dielectric loss is very low.

The capacitance variation depends on the shape of the rotary plates. These may be cut in a semicircular shape giving a linear capacitance variation or in elipsislike shapes giving linear frequency or linear wave-length variations. The term *straight line* is also used to mean *linear* in this connection. Hence, *straight-line frequency condensers* and *straight-line wave-length condensers* are terms also used.

24. METAL VACUUM TUBE.—This type of tube employs a metallic envelope instead of a glass envelope for maintaining the vacuum in the space occupied by the tube elements. Size for size, the metal tube is smaller than the glass tube. Also, the metal envelope functions as a radio-frequency shield for the tube elements and gives greater mechanical strength to the tube as a whole. The characteristics of the metal tubes are similar to their glass-tube counterparts of the same type number.

CHAPTER 4

TRANSMITTING-CIRCUIT PRINCIPLES

The various methods of operating a vacuum tube as a radio-frequency amplifier and as an oscillator have been described in the preceding chapter. It is the purpose of this chapter to explain the combining of these various functions into a modern transmitting circuit.

I. CONVENTIONAL CIRCUITS

4.1. General Transmitting Considerations.—There are certain principles which underlie the operation of *all* radio transmitters. All transmitters do not, however, incorporate *all* of these principles, the final design being determined by the service the transmitter is to perform. For example, the only difference between the modern radio-telegraph transmitter and the modern radio-telephone-transmitter circuit is that the telephone transmitter is fitted with modulating equipment, whereas the telegraph transmitter is not. In so far as the oscillator and the amplifiers are concerned, the theory of operation is the same whether the emission is a modulated or a continuous wave. Therefore, the principles explained in this chapter can be applied to all transmitters regardless of type. It is obvious, of course, that the radio-telephone transmitter utilizes all of the component parts of the transmitter here mentioned, whereas a radio-telegraph transmitter would utilize all except the modulating equipment and the audio monitor (compare Figs. 4-1 and 4-2).

4.2. Classification of the Radio Spectrum.—In view of the fact that the frequency on which radio circuits are to operate dominates as a

TABLE IVA.—USEFUL RADIO SPECTRUM

Frequency band in kilocycles	Megacycles	Designation	Abbreviation
10—30		Very low	VLF
30—300		Low	LF
300—3,000		Medium	MF
3,000—30,000	30	High	HF
30,000—300,000	300	Very high	VHF
300,000—3,000,000	3,000	Ultra high	UHF
3,000,000—30,000,000	30,000	Super high	SHF

controlling factor in their design, it is necessary to classify circuits and emissions with a common nomenclature which will at once identify the frequency range and the service in which it is used.

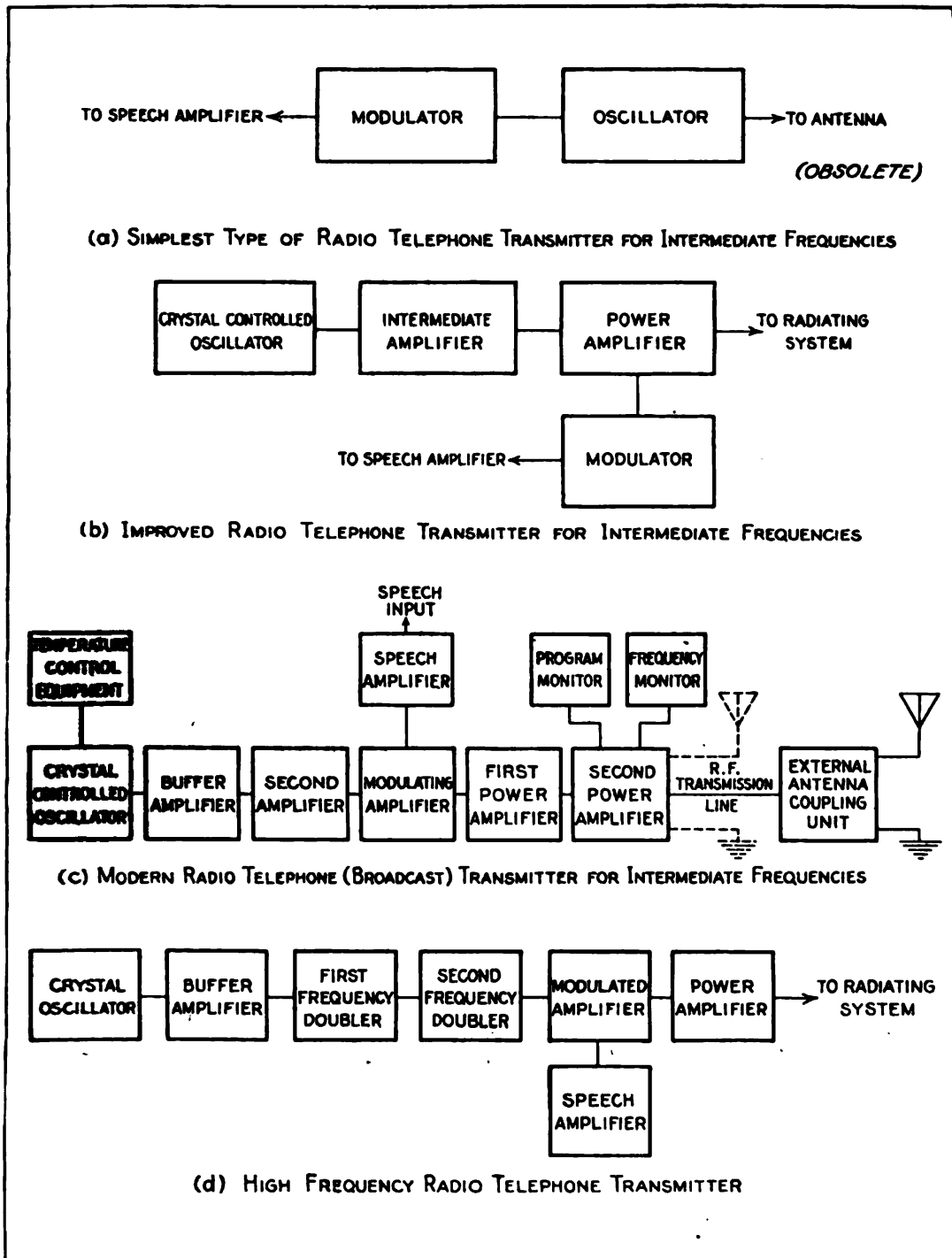


FIG. 4-1.—Block diagrams showing development of the radio-telephone transmitter.

The useful spectrum of radio waves is shown in Table IV A. This spectrum is divided into major working bands as shown in Fig. 4-3.

4.3. The Oscillator as a Transmitter.—The first vacuum-tube transmitters utilized the simple oscillator coupled directly to the radiating circuit as shown in Fig. 4-4. The circuit here shown is that of the Hartley oscillator which is typical of the simplicity of the transmitter as a whole. To increase the power of the transmitter it was only necessary to use a larger tube and increase operating voltages. Engineering conditions were ideal with the important exception that frequency stability could not be maintained, to any modern satisfactory degree, with the oscillator coupled directly to the antenna.

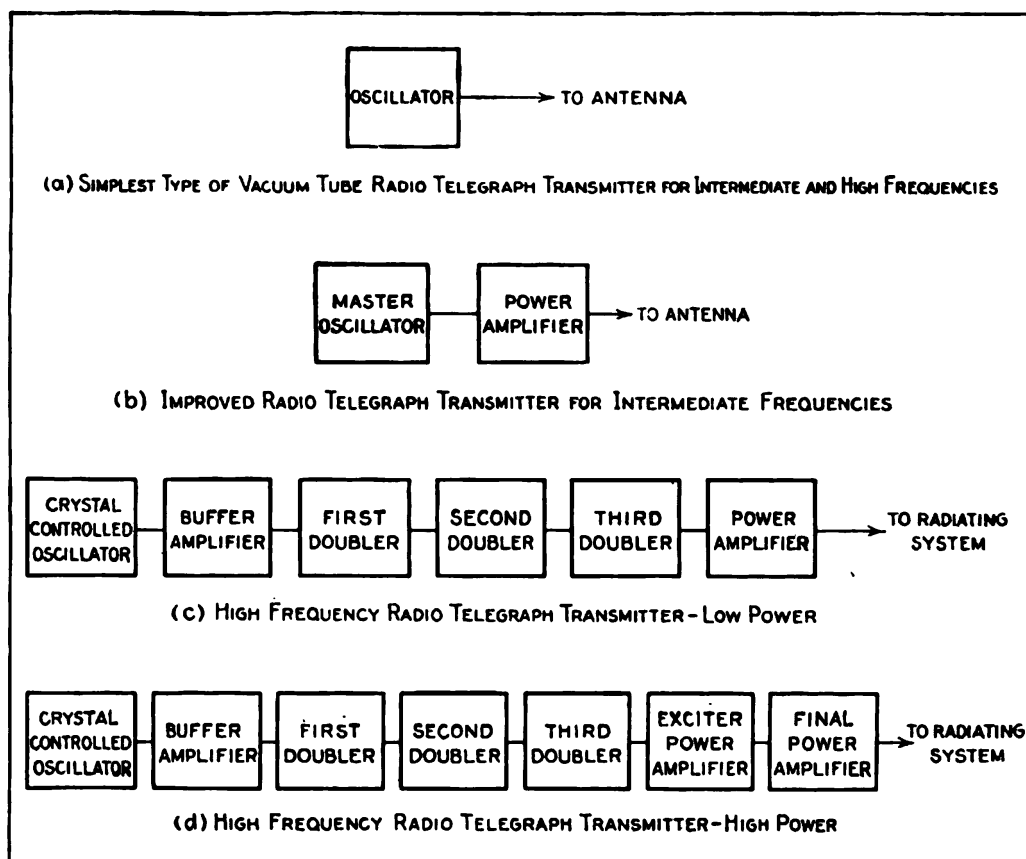


FIG. 4-2.—Block diagrams showing development of the radio-telegraph transmitter.

The reason for this poor frequency stability is apparent. The radiating system, that is, the antenna and ground, constitute the load on the tube which is inductively coupled to the oscillating circuit. One of the characteristics of the vacuum-tube oscillator is that its frequency of oscillation is determined by the reactances of the oscillatory circuit; if these reactances are in any way changed, the frequency is changed. Under practical operating conditions it was found that a slight change in the capacity of the open oscillatory circuit (antenna and ground) would reflect back to the oscillating circuit of the tube with a consequent change in its frequency.

This is a great disadvantage especially on board ship where the capacity of the antenna to the ground is subject to considerable change in high winds and during movements of the ship in a sea. This circuit is now considered obsolete and is only used where economy demands simplicity and where frequency-stability regulations are not rigidly enforced. It can be tuned to any high or medium frequency without modification.

4.4. The Oscillator-amplifier Transmitter.—It was pointed out in the preceding section that an oscillator when coupled directly to the radiating system is subject to severe frequency fluctuation. In order to overcome this deficiency the master-oscillator power-amplifier system shown in Fig. 4-5 was developed. This system has a decided advantage over the self-excited oscillator transmitter in that the frequency stability of the transmitter is greatly improved. This is due primarily to the fact that in this system the oscillator is not coupled directly to the antenna and, therefore, is unaffected by any changes in the antenna-to-ground capacity. The master oscillator in this particular circuit is of the Hartley type, although any of the conventional oscillators might be used with equally good results.

If the antenna-to-ground capacity does vary, the reaction upon the power-amplifier circuit will merely result in a decrease in the radiation efficiency owing to the change in the resonance conditions between these two circuits. In practice this is usually unnoticeable. The frequency stability of the transmitter is, therefore, much improved by using the master-oscillator power-amplifier system in preference to the simple oscillator alone as a transmitter.

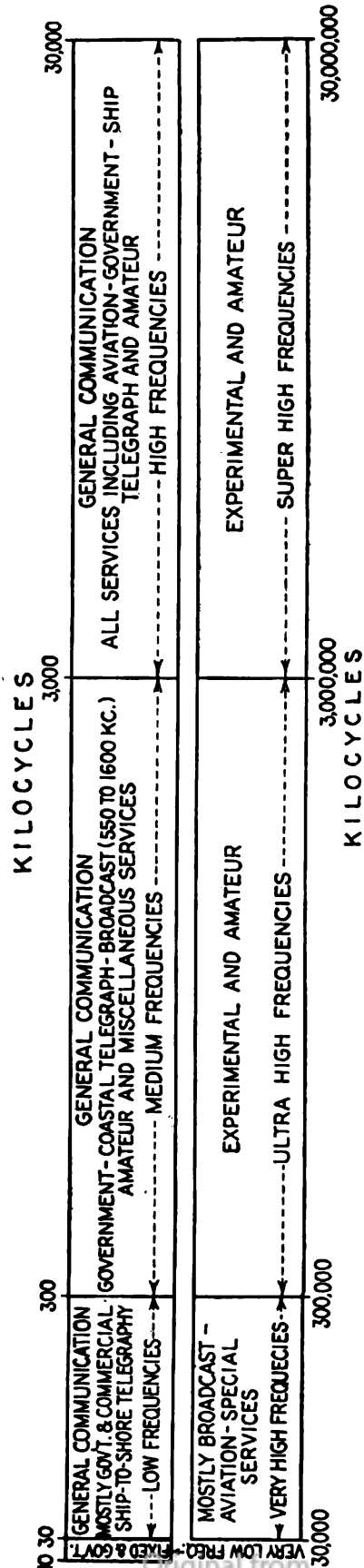


FIG. 4-3.—The radio-frequency spectrum and allocations.

The master-oscillator power-amplifier system is commonly referred to as the M.O.P.A. transmitter. The circuit shown here can be used on any frequency to which the oscillator can be tuned.

The frequency of the oscillations in Fig. 4-5 is determined by the circuit constants C_1, L_1 as before. The amount of plate and grid reactance is determined by the number of turns between the points AB and AC , respectively. These reactances will govern the degree of grid-

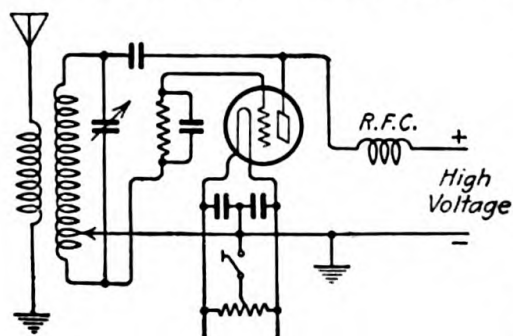


FIG. 4-4.—The oscillator transmitter.

voltage excitation E_2 across the grid-filament circuit of the oscillator tube.

When the tube is oscillating at a definite frequency as determined by the constants L_1, C_1 , the input (grid filament) to the power-amplifier tube may be connected across a portion of the inductance L_1 , so that it may be properly excited. In other words, the high-frequency e.m.f. built up

across the grid section of the oscillator coil AC may be applied across the input to the amplifier tube through the radio-frequency feed condenser C_4 and through the common ground connection to the filaments.

The amount of grid excitation across the amplifier tube is determined by the reactance of the feed condenser C_4 and the point at which the amplifier grid connection is made on the oscillator coil. The power

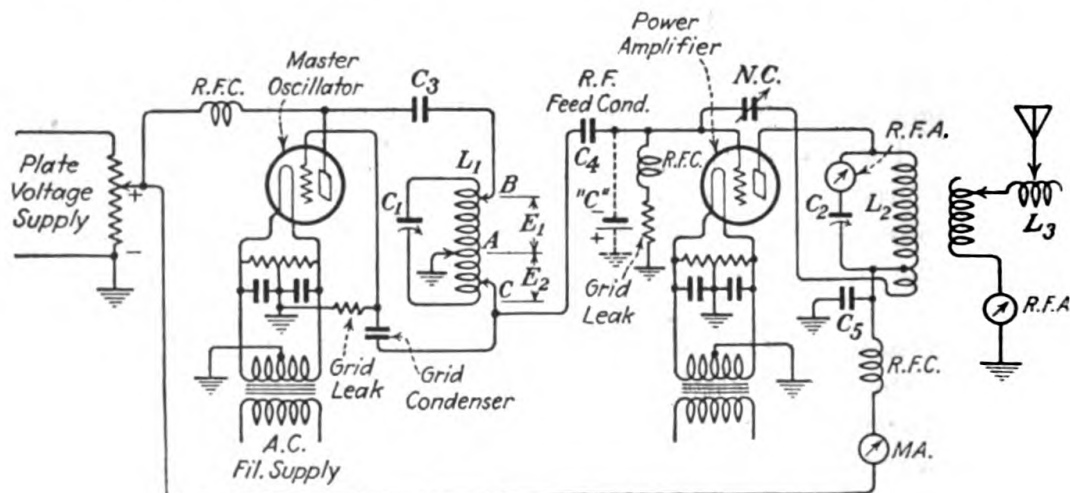


FIG. 4-5.—The M.O.P.A. (master-oscillator power-amplifier) transmitter.

amplifier is adjusted to the proper grid and plate voltage in accordance with the class of amplification in which the tube is to be operated, namely, class A, B, or C.

The output circuit L_2, C_2 is now adjusted to resonance with the master oscillator by an indication of the maximum current in the radio-frequency ammeter RFA in this circuit or by a maximum dip in the reading of the

plate milliammeter MA, after it has first been neutralized to prevent self-oscillation by properly adjusting the neutralizing condenser NC.

The antenna circuit is then tuned to resonance by adjusting the coupling and the tuning inductance L_3 for a maximum indication on the antenna radio-frequency ammeter.

Note: In an M.O.P.A. set, after bringing the antenna circuit to resonance, the power amplifier should again be slightly readjusted to resonance, minimum plate current. It must be realized that the antenna circuit, when tuned to resonance, should couple into the power-amplifier tank and appear as a power resistance load, but, owing to several variable factors, this coupled-in reactance will sometimes appear slightly capacitive or inductive. This means that the power-amplifier tank is not in exact resonance and, hence, the need for a slight readjustment of the power-amplifier variometer.

Condenser C_3 is the plate-blocking and radio-frequency by-pass condenser combined. Condenser C_4 is the power-amplifier radio-frequency by-pass condenser which serves as a low-reactance path for the radio frequencies in the plate circuit to flow through to the filament. This condenser in conjunction with the radio-frequency choke isolates the high-frequency currents from the power-supply source, thereby increasing the efficiency and stability of the amplifier circuit.

4.5. The Crystal-controlled Transmitter. General Considerations.—Comparing the block diagrams of Figs. 4-1 and 4-2, and considering the evolution of vacuum-tube transmitters, it at once becomes apparent that, as soon as a crystal-controlled oscillator is used to improve frequency stability, a multiplicity of tubes becomes necessary. At this point the reader is directed to compare the functions of the various tubes, starting with the oscillator, in the modern intermediate-frequency transmitter with the tubes in the modern high-frequency transmitter as labeled in the blocks.

It is evident that, in the high-frequency transmitters [Fig. 4-1(d) and Fig. 4-2(c) and (d)], frequency doublers follow the buffer amplifier instead of the simple radio-frequency amplifiers used in the intermediate-frequency transmitter [Fig. 4-1(c)]. These doublers perform the dual function of radio-frequency amplifier and frequency doubler. The necessity for each component part of the crystal-controlled transmitter will be explained in the remaining sections of this chapter. Wherever specific mention is made of apparatus construction we are referring to the Western Electric transmitter which is shown in Fig. 12-11, although not every circuit feature described in this chapter is necessarily found in or taken from this transmitter. We consider this transmitter an example of excellent design principles as used in intermediate-frequency transmitters.

All of what applies to the intermediate-frequency transmitter also applies to the high-frequency transmitter, the only difference between them being in the L and C values employed and in their propagation characteristics and operational difficulties.

As each component part of the transmitter is studied, its position in the circuit may be seen by referring to the block diagrams before mentioned. For their connection in the circuit as a whole the complete circuit diagrams of crystal-controlled transmitters (Fig. 12-11) should be referred to.

4.6. The Practical Oscillator.—Although the fundamental principles of the oscillator have been previously explained, a more detailed explanation of a practical oscillator, as illustrated in Fig. 4-6, follows:

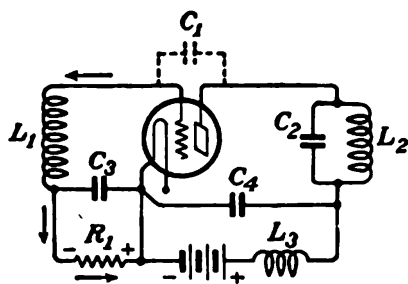


FIG. 4-6.—Oscillator circuit—series-feed plate supply.

The oscillatory circuit consists of inductance L_2 and capacity C_2 . The plate-filament capacity of the tube will be considered as part of C_2 . The feed-back circuit is the grid-plate capacity C_1 , which is generally quite small, but may be increased, if necessary, by adding an external condenser in parallel with C_1 . However, too large a total value of this capacity is undesirable because the circuit then will be unable to oscillate. In

general the output of the vacuum-tube oscillator increases as C_1 increases, up to certain limits depending upon the tube and circuits.

The energy fed back from the plate to the grid circuit through C_1 causes an alternating-current voltage to be built up across inductance L_1 and thus across the grid and filament. The tube then acting as an amplifier develops a correspondingly high voltage in the plate-filament circuit and across the oscillatory circuit giving the latter additional energy and keeping it in sustained oscillation.

The tube obtains its grid bias by means of the voltage drop across R_1 owing to the grid current flowing through R_1 . This current is caused by the positive halves of the alternating-current voltage impressed upon the grid-filament circuit making the grid positive during one half of each cycle. A positive voltage on the grid with respect to the filament causes current to flow from grid to filament through L_1 , R_1 , as indicated by the arrows in Fig. 4-6. When current flows through R_1 in this direction, the voltage drop across it is such as to make the filament end of the resistance positive and the grid end negative, thus biasing the grid negatively.

On the positive peaks of the alternating-current input voltage the grid is slightly positive because the bias across R_1 does not quite equal these peaks. This condition is necessary in order to have some grid current flowing through R_1 to produce this negative bias. That is to say, the voltage drop across R_1 is always just sufficient to permit enough grid current to flow in order to produce that grid bias.

Condenser C_3 acts as a by-pass to the input alternating-current voltage and also helps to maintain a steady bias voltage on the grid, for, when the input voltage is negative, no grid current flows and the voltage drop in R_1 is zero. However, C_3 was charged up with the bias voltage during the positive half of the cycle, and it tends to hold that charge and the voltage across it on the negative half. Of course, C_3 discharges through R_1 , but, if each is of large value, such as 0.1 mf. capacity for the condenser and 0.1 megohm for the resistor, the rate of discharge will be slow enough to allow time for the next positive half-cycle to be impressed on the grid.

Condenser C_4 is a by-pass for the plate circuit around the plate supply, and L_3 is a choke coil to prevent alternating current from flowing into the plate-supply circuit. These by-pass condensers and choke coil isolate the input and output circuits of the vacuum tube, thus restricting the coupling between the circuits to that of the coupling capacity C_1 .

Figure 4-7 illustrates a vacuum-tube oscillator employing inductive coupling for the feed-back circuit. As before, the oscillatory circuit C_2 and L_2 is coupled to the plate-filament circuit of the three-element vacuum tube; R_1 is the grid leak or grid-biasing resistor; and L_4 is a choke coil to prevent alternating current from flowing in the plate-supply circuit. C_1 and C_3 are blocking condensers to prevent short-circuiting either the bias or plate voltage. L_3 is inductively coupled to L_2 so that alternating current flowing in the latter induces a voltage in the former, thus impressing a feed-back voltage on the grid of the tube through C_1 . The amount of input voltage may be varied to the desired value by adjusting the tap on coil L_3 , L_3 . This will change the resonant frequency of the output circuit, and consequently condenser C_2 must be adjusted to compensate for the change of inductance of L_3 .

One point to be noticed in Figs. 4-6 and 4-7 is the difference in the method of connecting the plate-supply voltage. In Fig. 4-6 the series-feed method is used, while in Fig. 4-7 the parallel-feed method is employed. Each method has its advantages and special applications depending on circuit and load conditions. In a series feed the plate current flows through the output-circuit inductance. This permits the battery or other power-supply source to be practically at ground potential as far as alternating current is concerned, which is a desirable condition because it reduces losses and prevents intercoupling with other apparatus.

However, there is a disadvantage in that the output coil is at a high direct-current voltage above ground, necessitating additional insulation and also extreme care in the method of coupling to an external load.

In the parallel-feed system both difficulties just enumerated are eliminated, but the choke coil is called upon to withstand the full alternating-current output voltage. This means that some alternating current will flow through the choke coil L_4 and be lost to the output circuit. This loss may be very great unless the impedance of the coil is high, that is to say, the coil must be wound with many turns of wire to produce a large inductance and at the same time have a low distributed capacity shunting the winding. A properly designed choke coil will offer from 5,000 to 10,000 ohms impedance at the operating frequency, so one or more coils connected in series will prevent practically any current from flowing and thereby greatly reduce the possibility of circuit losses.

There are many possible circuit arrangements for vacuum-tube oscillators, as shown in the preceding chapter, each serving a different purpose under different kinds of operating and load conditions. However, most of them have the same inherent fault, namely, that of frequency instability.

The frequency of the vacuum-tube oscillator is that of the oscillatory circuit, which is dependent upon its own constants, plus the influences of the other circuits of the oscillator and the external load. It has been found that an oscillatory or output circuit with large capacity, low inductance, and very low resistance approaches the ideal circuit for frequency stability. In ordinary oscillators these conditions are desired, but the difficulty of building a coil with extremely low effective resistance, and a condenser of low resistance but of large capacity which must be variable, limits the design and construction, with the result that satisfactory frequency stability using an ordinary oscillator is not commercially practicable for a broadcast transmitter.

A parallel-resonant circuit with the characteristics of high reactance and low resistance is called a *high Q circuit*. Thus,

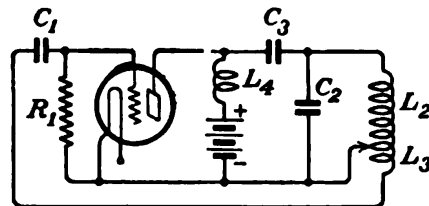


FIG. 4-7.—Oscillator circuit—parallel-feed plate supply.

$$\omega L$$

The ratio (Q) of inductive or capacitive reactance to the total resistance of the circuit should be a large value, from 50 to 200, depending on the frequency. In this discussion the total resistance of a circuit means the effective resistance of the coil, condenser, and interconnecting leads, plus the reflected resistance due to an external load, if there is one. Generally, the condensers used in high-frequency circuits have a low effective resistance, and consequently this factor is neglected in most calculations. However, this resistance may not be neglected when considering the output circuit of a vacuum-tube oscillator in which extreme frequency stability is desired.

4.7. The Mechanical Resonator.—While it is difficult to obtain a high- Q electrically resonant circuit for vacuum-tube oscillators, use is made of a peculiar characteristic of certain mechanical resonators to secure the equivalent of such a circuit. An example of a mechanical resonator or vibrator is a tuning fork. If the fork is given a blow, it will vibrate at a certain resonant frequency and continue to do so until all the energy imparted to it by the blow is dissipated. The frequency at which the fork vibrates is its resonant frequency and is analogous to the resonant frequency of an electrical circuit.

If the tuning fork is mounted in an arrangement, such as is shown in Fig. 4-8, it will be excited or operated by magnetic forces instead of the mechanical excitation described above. The coil wound on the iron core has flowing through it, when the key switch is closed, an electric current of sufficient amount to magnetize the core, which attracts one prong of the tuning fork to it. If the key is opened, current ceases to flow, neglecting the momentary surge and arcing at the switch points due to collapsing of the field, and the core becomes demagnetized and releases the tuning fork. If the key is closed and opened rapidly, the fork will be attracted and released accordingly.

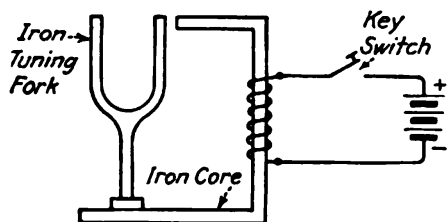


FIG. 4-8.—Mechanical resonator actuated by external e.m.f.

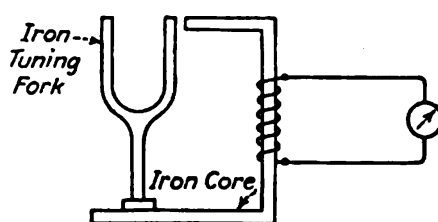


FIG. 4-9.—Mechanical resonator as a producer of e.m.f.

If we assume that the key is being closed and opened more and more rapidly, the fork responding to each operation, the number of vibrations of the fork will increase until finally this number will equal the resonant frequency as determined by mechanical excitation. If the current is stopped entirely, the fork will continue to vibrate for a time until its energy is dissipated.

The important point in this phenomenon is that below the resonant frequency considerable magnetic pull is required to operate the fork and, as soon as the current ceases, the fork will stop vibrating, while at the resonant frequency very little magnetic pull is required and, if the current is stopped, the fork will continue to vibrate for a time at its own frequency. This apparatus arrangement, operating at the resonant frequency of the tuning fork, is a form of mechanical resonator. The next step will be to consider the process reversed.

In Fig. 4-8, let us assume the iron core to be permanently magnetized and the battery and key to be replaced by a sensitive meter such as a zero-center galvanometer or an oscillograph element in series with the coil, as in Fig. 4-9. Now, if the prong

of the tuning fork is suddenly moved toward the upper end of the iron core, there will be a deflection of the meter in a given direction, and, if the fork is suddenly released, it will spring back to the original position and the meter will deflect in the other direction. The reason for this action is that, as the fork moves toward the iron core, the reluctance of the magnetic circuit was changed which caused a change in the magnetic flux traversing the magnetic circuit constituted by the core. The coil being wound on the core, and thus linking the flux, has a voltage induced in it, owing to the change in flux and current flow in the electric circuit, which causes the meter to deflect. The other half of the action is similar but in the opposite direction. The fork moving away from the core increases the magnetic reluctance, decreasing the flux, and this decrease again induces a voltage in the coil but in the reverse direction with resultant reversal of the meter deflection. As soon as the fork has come to rest and there is no longer a change in the magnetic circuit, the meter will again return to zero reading.

Now, if the fork is moved toward the core and released more rapidly, the above action is repeated and the meter is seen to oscillate about the zero point at a frequency or frequency period corresponding to that of the movement of the fork. Consider the mechanical excitation of the fork increasing more and more until finally the number of vibrations equals its resonant frequency, when it will vibrate easily with little excitation and will continue for a time with the excitation entirely removed.

The purpose of this experiment is to demonstrate that the vibrating tuning fork indirectly causes the production of alternating currents in the electric circuit, and therefore the whole process is reversible. That is, with the first arrangement in Fig. 4-8 the closing and opening of the key started and stopped the flow of current in the coil which through magnetic action set the fork into oscillation. And, conversely, the vibrating tuning fork through magnetic action sets up alternating currents in the electric circuit as indicated by the meter in the arrangement of Fig. 4-9.

4.8. The Crystal Resonator.—Still another form of mechanical resonator is the piezo-electric crystal. Several crystalline materials, such as quartz, tourmaline, Rochelle salt, and cane sugar, have the property of producing an e.m.f. when the crystal is mechanically strained (compressed or expanded). Furthermore, this action is reversible, so that, when an electric charge is impressed upon the crystal, the latter changes its shape. This remarkable characteristic is called the *piezo-electric effect* and is present in all the so-called piezo-electric materials to a greater or less degree, dependent upon the material, upon the form in which it is cut, and the manner in which the electric field is impressed. Rochelle salt is the most active in this property, but quartz has more mechanical advantages in that it is practically unaffected by light shocks, aging, and moisture. There is another advantage which is even more important; it is, that, due to its extreme hardness and low internal friction when vibrating, it has low damping and consequently a high-Q characteristic. This property, as we have seen before, is the chief characteristic necessary in the oscillatory circuit of a vacuum-tube oscillator where great frequency stability is required, and it is here that the quartz crystal plays the major role.

The piezo-electric crystal as a resonator may be considered equivalent to an electrical circuit such as is shown in Fig. 4-10. The series condenser C represents the rigidity of the crystal, the inductance L its mass, and R the internal resistance due to internal friction. The parallel capacity C_1 is mostly due to the capacity effect of the metal electrodes of the crystal holder acting like a condenser with the crystal as the dielectric. In practice, added to this is the capacity of the external connections and the grid-filament capacity of the vacuum tube when used.

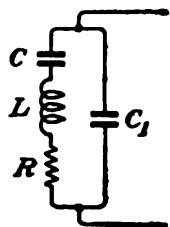


FIG. 4-10.
Electrical
equivalent
circuit of piezo-electric
crystal resonator.

Before proceeding further, one point must be clearly understood. Although the piece of quartz used as a resonator is generally called a "crystal," still it is not a whole crystal but only a section of one cut to certain dimensions and specifications. This section may be a thin slab in rectangular form, or it may be cut like a disk. The smaller, thinner sections used for very high frequencies are circular cut similar to a coin. Still another form, which is used for precision work, but not in commercial transmitters, is a flat ring. So let us proceed from here by calling the piezo-electric crystal a *quartz plate*, meaning a thin slab of rectangular or circular form, cut from a high-grade quartz crystal along a particular axis to make it more active piezo-electrically.

Figure 4-11 shows schematically a method of making electrical connections to the quartz plate. It is usually placed in a horizontal position between two metal electrodes or plates. The lower electrode furnishes a base for the quartz plate and is an integral part of the whole mounting. The upper electrode may be spaced above the plate, touch it, or be clamped to it. The crystal, like the tuning fork, must be permitted a certain amount of mechanical freedom in order to oscillate. The early practice was to permit the upper electrode to rest lightly upon the surface of the plate, a flexible connection being made to the electrode. The difficulty with this method was that the electrode would move about, and small particles of foreign matter would settle under it resulting in a change of spacing between the plate and the electrode. This condition caused considerable variation in frequency. To avoid such variations the quartz-plate holder is now constructed so as to clamp the plate rigidly in one position. Each electrode is made with an uneven surface of rises and depressions. The rises make contact and clamp the plate, while the depressions provide air spaces between plate and electrode, which allow the plate to oscillate or vibrate.

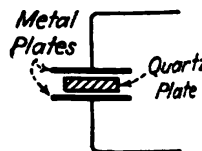


FIG. 4-11.—
Method of making
connections to
quartz plate.

Figure 4-12 shows a schematic diagram of a vacuum-tube oscillator incorporating a quartz-plate resonator. As previously explained, the tube with its associated circuits, such as filament and plate supply and automatic bias by means of R_1 , and tuned output

circuit, constitutes an amplifier. Feedback to the grid circuit is accomplished by the grid-plate capacity of the tube. The resonant circuit that determines the operating frequency of the oscillator is the quartz plate X_1 which is connected across the grid and filament of the tube. The condenser C_1 is of small capacity and is shunted across the quartz plate to obtain a vernier adjustment of the operating frequency by changing the resonant frequency of the equivalent electrical circuit of the resonator. The resistor R_1 acts as a load to the amplifier tending to stabilize it against external load changes and also to provide a means of coupling for the load. This resistance is only a few hundred ohms so that variations in coupling from a high impedance load do not affect the oscillator appreciably.

When the plate voltage is suddenly applied to the vacuum tube, a surge is produced in the output circuit charging C_2 , which tends to discharge through L_2 similar to the operation of an ordinary oscillatory circuit. This action in the output circuit causes a voltage to be built up across the plate and filament of the tube which, through the feed-back coupling of the grid-plate capacity, impresses a voltage upon the grid-fila-

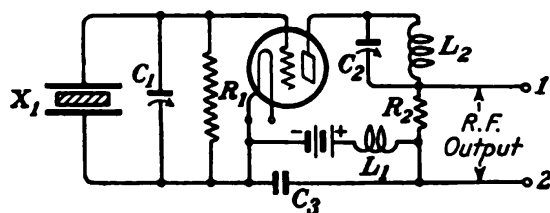


FIG. 4-12.—Oscillator with quartz-plate resonator.

ment circuit and across the quartz plate. The voltage in the latter circuit sets up an electrostatic field around the plate causing it to change shape slightly. As soon as the impressed voltage dies down, the quartz plate returns to its normal shape and in so doing produces a voltage across the electrodes and across the grid and filament of the vacuum tube. This voltage is amplified in the plate circuit, and some of the energy is fed back again to the grid circuit and the quartz plate which causes the latter to vibrate or oscillate, thereby applying a varying voltage to the grid. This action results in a continuous building-up process of the oscillations until the vacuum-tube oscillator is delivering its maximum power to its own and the external load for a given set of operating voltages and circuit constants. Actually the output circuit is not tuned to the exact frequency but to a slightly higher one so that it is somewhat inductive at the operating frequency. This condition provides greater stability and also aids the quartz plate to start vibrating more readily.

The main factors which determine the operating frequency of the vacuum-tube oscillator and also its stability are: the type of cut and mode of vibration, whether longitudinal or lateral, of the quartz plate; its thickness; the relationship between the plate and the electrodes; the amount of capacity externally connected across the electrodes; and the temperature of the quartz plate. Other factors, such as power supply and external load conditions, affect the frequency only slightly in that they cause minor vibrations of the load across the quartz plate itself.

The type of cut and mode of vibration of the plate depend upon the frequency desired, the type of operation, and the design of the oscillator. These are fixed properties in any particular plate. The thickness of the plate required depends principally upon the frequency of operation of the crystal. The relationship between plate and electrodes has become a fixed quantity owing to the clamping process explained above. The external capacity, once the oscillator is designed, built, and adjusted, is a question of the grid-filament capacity present in the tube and the vernier condenser C_1 . The former is generally of the order of 5 or 10 mmf. and changes very little as a result of fairly uniform construction in manufacture. The vernier condenser is designed to be

adjusted for small variations of frequency of the order of 10 or 20 cycles, but once adjusted it is seldom varied. This leaves the temperature as the one remaining factor, and it is actually of major importance.

The temperature of the quartz plate is maintained at a nearly constant value by placing the plate and its holder, together with a heater and thermostat, in a heat-insulated chamber. The chamber may be a metal box carefully lined inside with an insulating material such as Celotex. It is sometimes advisable to enclose this entire unit along with the vacuum tube and associated circuits in another insulated chamber, but this is only for very accurate standards.

4.9. The Temperature-control Chamber.—Figure 4-13 shows an arrangement of a temperature chamber for a quartz-plate resonator. This is the Western Electric type which is used in many broadcast

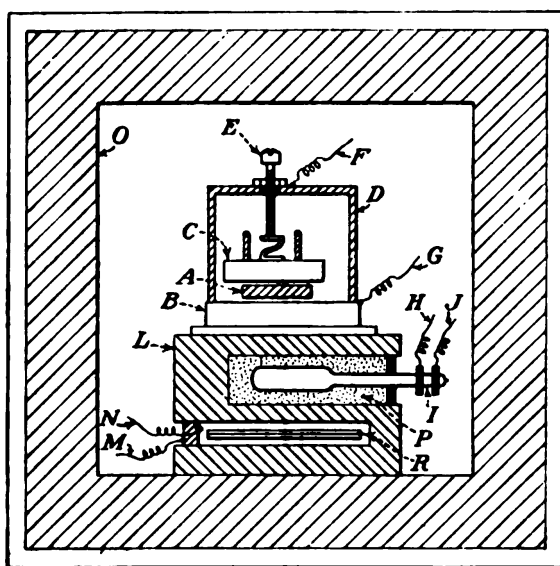


FIG. 4-13.—Temperature chamber for quartz-plate resonator (see text, Sec. 4.9, for an explanation of parts).

stations. The quartz plate *A* rests upon the lower electrode *B* and is held in place by the clamping action of the upper electrode *C* with its spring and adjusting screw *E*. A locknut fixes the screw once it is adjusted. The shell *D*, which surrounds this assembly and fastens to the lower electrode, is an insulating material such as Isolantite. The lower electrode is connected thermally to the heater unit through a thermal filter. The heater unit *L* contains the thermostat *I* and heater element *R*. Graphite powder *P* holds the thermostat in place, and leads *H* and *J* make electrical connection to the mercury contacts within the stem. The heater element *R* may be of the wire-wound or grid type, carefully insulated electrically from the copper casting of the heater unit, with connecting leads *M* and *N* brought outside. A thermal-insulating housing *O* completely encloses all this apparatus, tending to maintain the internal temperature constant. The whole unit is assembled in a metal box designed to be mounted in the radio transmitter. All the leads including those from the electrodes are brought through the box to a

terminal strip where connections are made to the grid and filament of the vacuum-tube oscillator and also to the temperature-control circuits, shown schematically in Fig. 4-14.

The purpose of the control circuit is to provide heat for the quartz plate and maintain the temperature of the plate as nearly constant as possible. Heat is not essential to the operation of the quartz resonator, but, as room temperatures may vary as much as 50°F., the simplest method is to heat the plate considerably above room temperature (to about 90°F.), so that these changes are less effective, and then maintain a constant value. As shown in the schematic drawing, heat is supplied by passing current through the resistor R . This current is obtained from the transformer S_1 , the circuit being completed through the plate filament of the control vacuum tube V_1 . This tube is generally a gaseous-type rectifier with a low internal voltage drop and resembles the ordinary high-vacuum three-element tube in that a control grid is used.

The control action is not one of regulating heat to meet varying conditions but is an intermittent process. Normally the circuit through the thermostat is open, because the mercury column within is normally low. This condition leaves the grid of the vacuum tube connected through resistor R_1 to what we shall call the positive side of the transformer S_2 with respect to the mid-tap which is connected to the filament through transformer S_2 . By "positive side of the transformer" is meant that the windings are so phased that during the half of the alternating-current cycle, when the plate of the tube is made positive, the grid is also made positive, all with respect to the filament. Under this condition the tube is conducting, and current flows around in the plate circuit, heating the resistor R . During the other half of the cycle, both plate and grid are negative and no current flows. Thus we have a half-wave rectifier supplying current to the heater, the tube being conducting on the positive half-cycle because the control grid is also positive.

After the heater element has been in operation for some time, the temperature inside the chamber rises. Then the mercury in the thermostat expands, short-circuiting the contacts in the stem. This completes the circuit of the entire winding of transformer S_2 through resistor R_1 and the thermostat contacts. All the voltage drop is consequently across R_1 , the control grid is now connected to the left or "negative" side of the transformer, that is, the grid is negative whenever the plate of the tube is positive, it is biased to plate-current cutoff, and, of course, no plate current flows. On the negative half of the cycle the grid becomes positive, but still no plate current flows because the plate of the tube is now negative. Therefore, the action of the thermostat has been to change the phase relation of the voltage on the control grid and thus indirectly prevent further heating of R .

Eventually the heat in the chamber will escape through the walls, and the temperature inside will drop. The mercury in the thermostat also drops, opening the contacts in the stem and returning the control tube to its original condition, and the heating of

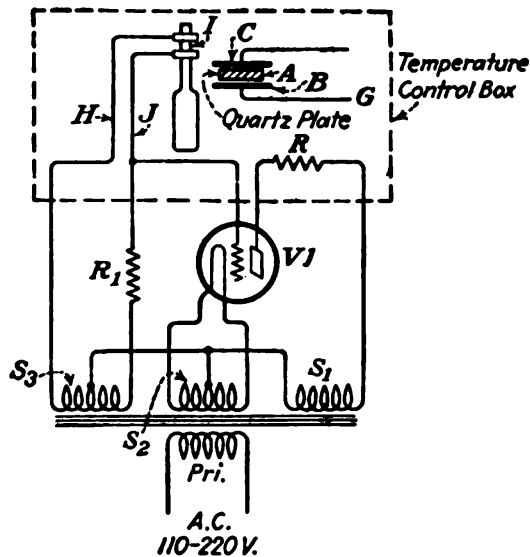


FIG. 4-14.—Schematic diagram of connections in temperature chamber.

R begins again. Thus the whole cycle consists of heating R and then permitting it to cool. The heating period may take 30 sec. and the cooling period 50 sec., depending upon many factors of design of the whole system. One may think the quartz plate would also be alternately heated and cooled, but this condition is largely prevented by a specially designed heat filter which tends to iron out these changes and provide a constant flow of heat to the plate.

4.10. The Buffer Amplifier.—The main purpose of this stage, shown in Fig. 4-15, is to function as a first voltage amplifier and at the same time isolate the oscillator from the succeeding amplifiers in the radio transmitter as far as the carrier frequency is concerned. The buffer amplifier usually consists of a single vacuum tube biased to at least the I_p cutoff point and so operated that the positive peaks of the radio-frequency voltage applied to the grid and filament of the tube from the oscillator do not exceed the grid-bias voltage. Under this condition the

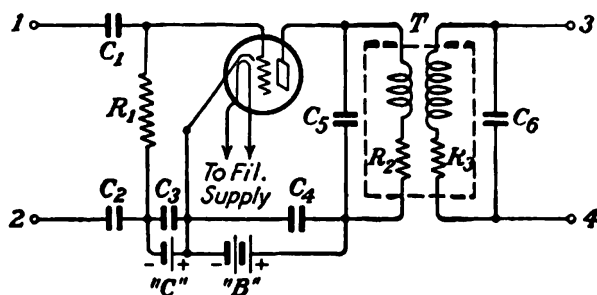


FIG. 4-15.—Circuit of buffer or first amplifier.

amplifier draws no grid current and consequently there is no changing load on the oscillator. If, however, an appreciable amount of grid current is drawn with the resultant variations of load on the oscillator tube, there would be variations in the frequency owing to the slight changes of the resonant frequency of the quartz-plate resonator. Hence, by employing a buffer-amplifier stage, the oscillator is permitted to work into its own fixed-load resistance, supplying only a radio-frequency voltage to the buffer amplifier.

In the schematic diagram of the vacuum-tube oscillator (Fig. 4-12) is seen the load resistance R_2 across which is developed the carrier-frequency voltage which is to be applied to the buffer amplifier. Figure 4-15 is a schematic diagram of this amplifier. The input voltage is applied to terminals 1 and 2 and is impressed on the grid and filament through the blocking condensers C_1 and C_2 and the by-pass condenser C_3 , which shunts the grid-biasing potential. The blocking condensers C_1 and C_2 prevent a short circuit of the grid-biasing resistor R_1 by the load resistance in the oscillator. The negative bias is applied to the grid through resistance R_1 which is of a large value, such as 0.5 megohm, to prevent excessive losses in the input radio-frequency current. Owing to the fact that no grid current is permitted to flow in the grid circuit, it is advisable

to use a large resistance for R_1 so that the input impedance is kept as high as possible. Condenser C is a by-pass for the plate-supply battery.

The output or load circuit of the buffer amplifier may be of the type illustrated in Fig. 4-15 which consists of an air-core, shielded, fixed-tuned transformer T for coupling to the succeeding stage, at the terminals 3 and 4. This type of transformer offers a fairly constant impedance into which the tube may work and has a good transmission characteristic or frequency response over a considerable band width. With proper design, the transmission characteristic may be constant to within 25 per cent over the entire broadcast band. It is generally unnecessary to neutralize this amplifier because of its relatively low power and gain. The primary of the transformer is tuned to a given frequency by the condenser C_1 , while the secondary is tuned to a slightly different frequency by the condenser C_2 which consists of a fixed condenser and the grid-filament capacity of the succeeding tube. The result of the two tuned circuits when coupled together is a double-resonant frequency looking into the primary circuit from the tube. The peaks of the double resonance may then be caused to spread apart by the proper adjustment of the coupling between the two windings and the peaks then flattened out by the resistances R_2 and R_3 of the windings. Hence the resultant frequency-response curve results from two widely separated very flat resonance curves which have merged into each other effectively, thus producing a uniform frequency characteristic over a wide band. Once this adjustment has been made, the transformer remains unchanged and the condensers C_1 and C_2 may be fixed capacities.

4.11. The Second Amplifier.—The general block diagram of a radio transmitter as illustrated in Fig. 4-1(c) indicates a second amplifier (schematic diagram shown in Fig. 4-16) coupled to the buffer stage.

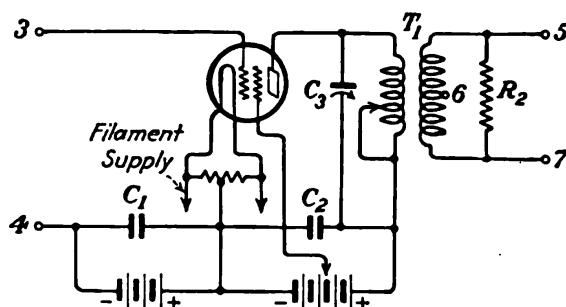


FIG. 4-16.—Circuit of the second amplifier using screen-grid tube explained in Sec. 5.2.

It was shown that the buffer amplifier served a double purpose; first, that it is used chiefly to isolate the oscillator from the other circuits in order to obtain a maximum frequency stability, and, second, to function as a low-gain voltage amplifier. The second amplifier, however, must operate not only as a voltage amplifier but also as a power amplifier as shown in Fig. 4-16.

A true voltage amplifier draws no power from the preceding stage and delivers practically no radio-frequency power to the succeeding stage. There is, of course, some quantity of power loss due to the coil and the circuit resistance, but these are reduced to as low a value as possible in the design and construction. The voltage amplifier is usually a high-gain device, in which a small input voltage is received and a large output voltage is delivered to the succeeding stage. The coupling transformer is generally tuned in the primary and sometimes also in the secondary, and the primary-to-secondary turn ratio is quite large.

A true power amplifier requires a large value of input voltage and considerable input power while delivering a large value of output power with some voltage gain. The output transformer may therefore have a relatively few number of turns on the secondary and only enough primary inductance to obtain the proper impedance match for the tube. Both of the windings are generally tuned where high-power amplification and a maximum transfer of energy are required. The output transformer for this type of amplifier, therefore, may be a step-down transformer with few turns but using large wire.

It has previously been shown that voltage amplifiers employ vacuum tubes with a high amplification factor (μ) and a large plate resistance (R_p), while at the same time the impedance of the output circuit is made as high as practical design will permit. Power amplifiers, on the other hand, generally employ vacuum tubes with a low amplification factor and plate impedance in order that they may be capable of handling large amounts of power with minimum distortion. The output impedance is usually adjusted to match the plate resistance of the tube, in order to obtain the maximum transfer of energy from the tube to the output.

For certain purposes such as in a modulated amplifier, the above conditions may not be adhered to; that is, this stage may be both a voltage and a power amplifier, requiring a small power input and delivering a fairly large power and voltage output, but all with the chief characteristic of linear amplification in which the amplified output is a faithful reproduction of the input voltage. This type of amplifier will not be so efficient as a true voltage or power amplifier, and its overall gain will be lower than if it were so used.

In the radio transmitter now under consideration, the second amplifier falls in the third class; that is, it is used for both voltage and power amplification. For reasons yet to be explained, it is not used for the purpose of providing a linear amplifier.

In the schematic diagram of this amplifier as given in Fig. 4-16, it is seen that a screen-grid vacuum tube is employed. The radio-frequency input voltage is obtained by connecting terminals 3 and 4 to the corresponding terminals on the buffer amplifier. The screen-grid tube is used for two reasons: one is that it is unnecessary to neutralize this stage when this type of tube is used, and the other is that a means is then provided for controlling the input to the modulating stage to follow, and also controlling the radiated output of the transmitter.

When it is desired to increase the radio-frequency output of the second amplifier, the screen-grid voltage is increased slightly, effectively reducing the plate resistance and increasing the plate current and output of the tube. Conversely, when the output is to be decreased the screen voltage is lowered.

Owing to the fact that the modulating stage follows the second amplifier, it is necessary to dissipate a certain amount of the radio-frequency energy in the load resistance R_2 in order to obtain the proper voltage across terminals 5 and 7 of the transformer T_1 . Hence the second amplifier must deliver some power to the load resistance (and perhaps some to the input of the modulating stage depending on the type of modulation) and also amplify the voltage impressed across its grid and filament. Screen-grid tubes owing to their design have a fairly high plate resistance and amplification factor making them ideal voltage amplifiers. When this type of tube is called upon to deliver power to a load, it needs a larger input voltage and some power, because of the large values of grid current resulting from the high input voltage.

Figure 4-16 shows the usual by-pass condensers C_1 and C_2 , plate supply, and output transformer T_1 . The primary of T_1 is tapped in order to cover the required frequency band in tuning in conjunction with the variable condenser C_3 . The load resistance R_2 is a specially wound unit designed to have practically no inductance or capacity. The value of R_2 is determined by the voltage to be impressed on the grid and filament of the succeeding stage and by the power to be dissipated in the resistance from the second amplifier. Hence, assuming that the succeeding stage required an input voltage of 100 volts, and assuming that the second amplifier was to deliver 10 watts to the resistance, then, by Ohm's law ($E = IR$), and the power equation ($W = EI$), the resultant equation ($R = \frac{E^2}{W}$) gives $R = \frac{100^2}{10} = 1,000$ ohms. Therefore, when the second amplifier delivers 10 watts to the resistance R_2 , there will be built up across it 100 volts which is impressed on the grid and filament of the modulating stage.

4.12. Harmonic Producers: Frequency Multipliers.¹—Systems which are rich in the generation of harmonic frequencies may be used to advantage in radio-frequency amplifiers for the purpose of *frequency multiplying*.

It has been shown that all single-tube amplifiers possess this characteristic due to the non-linearity existing in the plate-current curve when signal e.m.fs. are applied to the grid. Although these conditions are highly undesirable in audio-frequency amplifiers, they may be used to advantage where frequency doubling or tripling is required. In reality, therefore, any amplifier which is adjusted to the point at which high plate distortion results may be used as a frequency-multiplying device.

There are two distinct types of frequency multipliers, namely, that in which the distortion takes place in the plate circuit, and the other in which the distortion takes place in the grid circuit. The former is known as a plate-distortion harmonic generator and the latter as a grid-distortion harmonic generator.

In the plate-distortion method the plate potential should be considerably higher than for normal operating conditions, and the grid bias should be so adjusted that the tube is operating slightly in excess of the I_p-E_c .

¹ For the sake of continuity, if only broadcast transmitters are being studied, it is desirable to leave this section for later and separate consideration as Sec. 4.13 appropriately follows Sec. 4.11 at this point.

cutoff value so that the input signal voltage will not cause any grid current to flow. The grid-bias voltage, incidentally, is one of the most important adjustments for proper harmonic generation and should be carefully varied for each harmonic change required. The conditions for harmonic generation are therefore almost identical with those of the adjustment of a class B amplifier with the exception that the higher plate-voltage and grid-biasing conditions produce a much more asymmetrical wave form. This is due to the fact that, if the input signal voltage is brought up to the point at which it equals the grid-bias voltage at peaks, it will produce short-duration pulses in the plate circuit.

In the grid-distortion method a series impedance is connected in the grid circuit to form a parallel-resonant circuit properly adjusted to the harmonic frequency that is to be generated. Now, since a parallel-resonant circuit will represent a high impedance in the grid circuit to the resonant-harmonic frequency, the exciting grid voltage will develop a considerable potential difference across it. Now, if the grid bias is adjusted to the point in which a very small grid current will flow during the positive half of the cycle, this small current will be of a highly damped character due to the dissipation of the high series impedance. Consequently, the resultant grid signal voltages developed across the tube will be highly damped. Thus, if the input grid voltages represent short-duration pulses (highly damped pulses are rich in harmonic content), these will be amplified in the plate circuit in accordance with the general considerations of vacuum-tube circuit amplifying ability.

Perhaps the most frequent application of the frequency-multiplying arrangements is that of the quartz-plate oscillator for high-frequency transmission, although the principle may be applied to any conventional type of oscillator-amplifier system.

For example, if it is desired to operate a transmitter at a frequency of 15 megacycles (20 meters), the oscillator must be capable of delivering sufficient power to excite the grids of the succeeding radio-frequency amplifying stages. This would require an oscillator capable of developing at least 5 watts of output power. If, therefore, an oscillator tube is to generate this amount of power, a considerable voltage must be developed across its input circuit through feedback. Consequently, if a quartz crystal is used to control the frequency of the oscillations to be generated, the strain developed across it may subject it to rupture and possible splitting or cracking. It will be remembered that a crystal, to operate at very high frequencies, must be very thin in its structure. It is, therefore, possible to use high-frequency crystals with assurance of stability, only if the power output requirement is very small. It is necessary, therefore, when it is desired to use a crystal-controlled oscillator for frequencies of 15 megacycles or more, that a system of frequency doubling be used which will enable the crystal circuit itself to operate at a lower frequency and thereby permit the use of a thicker crystal.

Figure 4-17 illustrates a typical circuit arrangement of a crystal-controlled oscillator and frequency-doubling amplifier.

Let us assume the crystal to be properly ground to oscillate at a frequency of 3,750 kilocycles (80 meters) and to be connected in the oscillator circuit with tube V_1 . The plate circuit of the oscillator L_1C_1 is adjusted to resonance with the crystal fre-

quency (80 meters). The voltage developed across L_1C_1 may then be applied to the input of the first frequency-doubling tube V_2 through the coupling condenser C_2 . The amount of grid-excitation voltage being determined by the position of the tap on L_1 , $E_g = IZ$, where I is the radio-frequency tank current and Z the impedance from the tap to the ground. Now, if the plate circuit L_2C_3 of V_2 is adjusted to the second-harmonic frequency or 7,500 kilocycles (40 meters), and the plate and grid-bias voltages adjusted in accordance with the grid- or plate-distortion methods described, the fundamental frequency voltage E_g of V_1 will develop in the plate circuit L_2C_3 an oscillating current of 7,500 kilocycles (40 meters). If the voltage developed across L_2C_3 is insufficient to excite the grid of V_3 , a buffer stage is usually used after the oscillator, which delivers a larger power at the fundamental frequency. A large size V_1 may then be used which can properly excite V_3 . The voltage now developed across L_2C_3 at the frequency of 7,500 kilocycles (40 meters) will, as before, develop a frequency at the second harmonic of 7,500 kilocycles or 15 megacycles (20 meters), in

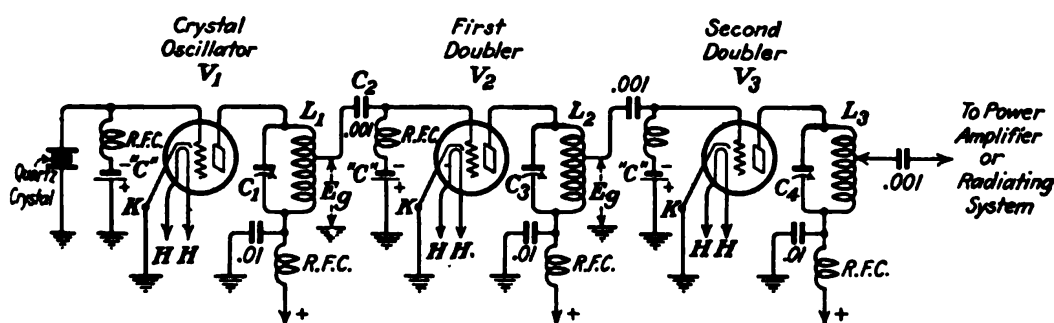


FIG. 4-17.—Frequency-doubling amplifier circuit.

L_2C_3 , provided, of course, that the plate and grid-bias voltages are applied in accordance with harmonic-generation procedure, and that the load circuit of V_3 L_3C_4 is adjusted to 15 megacycles. Now, since this is the desired frequency to be transmitted, the output of L_3C_4 may be coupled to the radiating system or it may be amplified through a number of voltage and power-amplifier stages to obtain the desired antenna output.

Great care must be taken that all stages are well shielded and that all circuits are properly isolated by grid- and plate-filtering systems. Doublers do not generally require neutralizing.

If the output circuit of a frequency-multiplying tube is to provide other than a single-harmonic frequency, the output load is generally an untuned inductance so that any desired harmonic may be obtained. The impedance of this inductance, however, should be made variable by taps so that the load may be regulated to the proper impedance match for the particular harmonic desired.

4.13. Modulation.—With the exception of the vacuum-tube oscillator with its crystal control for high-frequency stability, the modulated-amplifier stage is probably the most difficult part of the transmitter to design, adjust, and operate from an electrical standpoint. It is here that the single radio-frequency wave must be converted into a very complex wave by the incoming speech or music from the audio amplifiers in such a manner that when the signal is demodulated by the receiver the

resulting speech or music is a faithful reproduction of the original program or other speech.

By modulation is meant the process whereby the frequency or amplitude of the radio wave is varied in accordance with an audio wave. There are two ways of modulating a radio wave, by either frequency or amplitude modulation. Frequency modulation is that method in which the fundamental carrier frequency is made to change in accordance with an audio frequency. This system invented by Edwin H. Armstrong, the famous American radio inventor, has been widely adopted by broadcast stations and for general communication systems. Frequency modulation is fully treated in Chap. 8. Modulation as used for the production of A2 (modulated continuous waves) is discussed in Chap. 13. In the present chapter, we shall confine our discussion to amplitude-modulation systems.

In amplitude modulation the carrier frequency remains constant, but its amplitude is made to change in accordance with the audio frequency. The carrier wave normally has a certain value or amplitude. Thus, when the audio-frequency wave is impressed on the modulating stage, a sort of valve action occurs and the carrier wave becomes larger or smaller in accordance with the action of the audio wave. For full modulation, when the positive peak of the audio wave reaches its maximum, the peaks of the carrier wave become double the value reached when no modulation is occurring; and when the other half of the audio wave reaches a maximum, that is, in the negative direction, the carrier-wave peaks are reduced to zero.

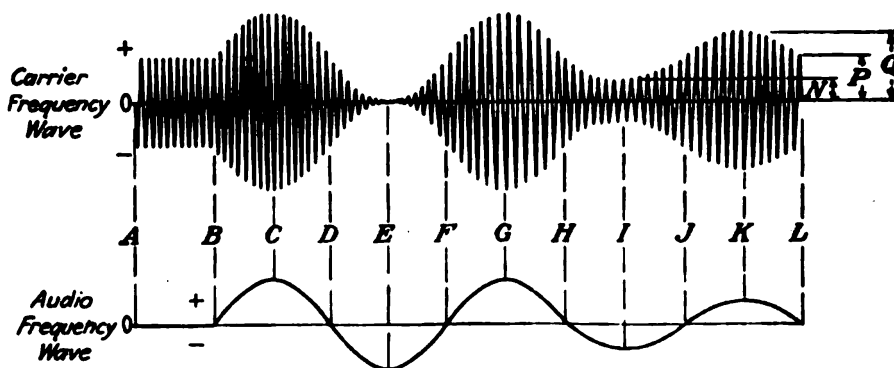


FIG. 4-18.—Modulating effect of audio-frequency wave on carrier frequency.

Figure 4-18 shows the conventional method of illustrating graphically what occurs during modulation. The upper wave represents the alternations of the carrier-frequency current while the lower wave represents the alternations of a single audio-frequency current. Along the horizontal time axis the distance AB indicates the condition existing before the audio wave is applied. The carrier wave is then seen to alternate about the zero axis with peak values of current remaining constant at an amplitude equal to P. At the point B on the time axis, the audio wave starts to increase in the positive direction causing an increase of the carrier-frequency output of the modulating stage. At point C the peak of the audio wave causes the maximum

output and then starts decreasing to D where the carrier is again normal. The audio wave now starts in the negative direction, decreasing the carrier still further, until point E is reached where the carrier output is zero. Further on, at the point F , the audio wave is zero, having completed one alternating cycle, and the carrier is again back to normal and the entire operation is ready to be repeated.

4.14. Modulation Percentage.—The audio wave was chosen of such amplitude during the time interval B to H , that full, or 100 per cent, modulation resulted. Now if the amplitude of the audio wave were decreased to half that value, such as is shown during the time interval H to L , then the amount of modulation would be only half of that first obtained. The measure of the amount the carrier wave is changed is expressed by a value M called the *modulation factor*, usually expressed as the *percentage of modulation*. This is a measure of the depth of the envelope of the modulated carrier and is expressed by the equation

$$M = \left(\frac{I_{max} - I_{min}}{2I_0} \times 100 \right) \text{ per cent} \quad (2)$$

where I_{max} is the maximum peak value of carrier current (indicated by the special commonly used symbol Q in Fig. 4-18); I_{min} is the lowest peak value of current (indicated by N); and I_0 is the normal peak value of current when no modulation is occurring (indicated by P).

Taking the time interval B to F on the modulated carrier wave, the amplitude Q is seen to be twice the normal value P , while the amplitude N is considered to be zero. Substituting these values in the formula above, the percentage of modulation is found by the equation

$$M = \frac{Q - N}{2P} \times 100 = \frac{2P - 0}{2P} \times 100 = 100 \text{ per cent} \quad (3)$$

If the audio wave has a smaller amplitude than that given above, say, for example, the amplitude in the interval H to L , then the percentage of modulation will be less, that is, 50 per cent. Therefore, the percentage of modulation may be any value from 0 to 100 depending upon the amount of audio frequency applied to the modulating stage, but it can never exceed 100 without introducing distortion. If more audio frequency power is applied to the modulating stage than the amount necessary to produce 100 per cent modulation, then the carrier is said to be overmodulated and the amount of distortion caused in the audio-frequency component is increased as the overmodulation is increased.

4.15. Carrier and Side-band Relations.—The theory of modulation may best be understood by considering two important viewpoints, namely, one in which the modulation process may be visualized as a wave of constant frequency with varying amplitude (amplitude modulation) and one in which the wave is expanded into components of the carrier and the side-band frequencies.

Amplitude modulation as shown in Fig. 4-18 is unquestionably a very definite picture, and serves to illustrate how a wave form may be varied in its amplitude by variable resistance or reactance characteristics. This condition may be readily understood by considering the explanations in Secs. 4.13 and 4.18. It is simply a method of expressing the physical change of the wave shape into various amplitudes, and is brought about by the application of an audio-frequency wave upon the carrier frequency. Regardless of whether or not this amplitude change is brought about by grid or plate modulation, it is still visualized as amplitude modulation as shown in Fig. 4-18.

The side-band viewpoint, on the other hand, may in some cases present a more desirable picture since it illustrates that during the process of modulation, the modulated signal appears as three components (or more) on three (or more) different frequencies. This viewpoint may be clearly seen from the illustrations in Fig. 4-19(a) and (b).

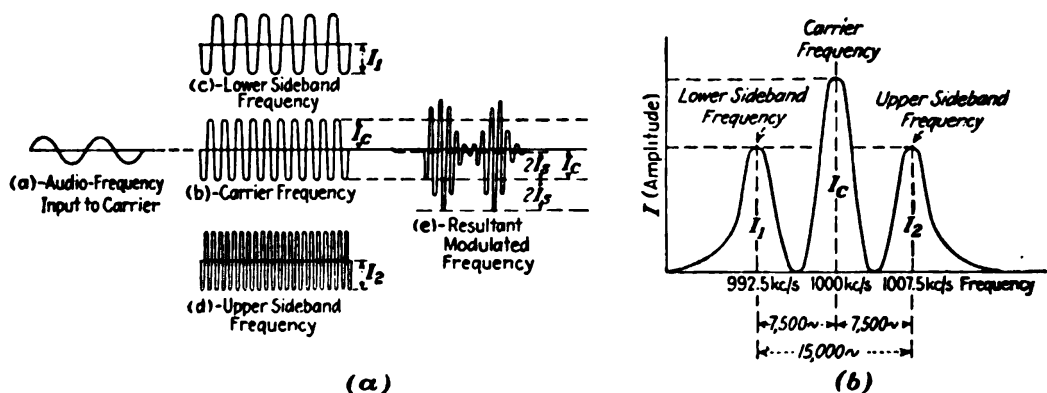


FIG. 4-19.—Relationship of side bands to carrier frequency.

Let us assume a carrier frequency of 1,000 kilocycles modulated by a steady audio frequency of 7,500 cycles. This is generally the highest audio frequency transmitted by broadcast stations, except in special cases where high-quality telephone lines of 8,000 cycles or better are used. It will be seen from both illustrations that the impressed audio frequency will result in the generation of two additional frequencies, one of 1,007.5 kilocycles and another of 992.5 kilocycles. These are known as the *upper* and *lower side bands*, respectively. Now, since this interaction of frequencies occurs in the transmitting circuit, these reactions will produce a resultant amplitude change in the output wave form and its form will be as illustrated in (e) of Fig. 4-19(a). In other words, the resultant wave shape (e) represents the instantaneous sum of the three radio frequencies (b), (c), and (d). It is this wave which represents the true picture of the modulated output emanating from the transmitter during the process of modulation. The ratio of the sum of the two side bands divided by the carrier frequency is the *modulation factor*, expressed

$$M = \frac{I_1 + I_2}{I_c} = \frac{2I_s}{I_c} \quad (4)$$

Definite proof that side bands exist can be obtained by placing a sharply tuned calibrated radio-frequency amplifier with a crystal filter and an output indicator of the oscillograph variety in the vicinity of the transmitter. If the receiver is tuned to the unmodulated carrier frequency, and the received frequency measured and noted, and the carrier then modulated at, say, 7,500 cycles, and the circuit tuned to a point 7,500 cycles above or below the carrier frequency, a resonant peak at the two side bands will be indicated. Then, if the energy for each of the three frequencies is plotted, a characteristic such as is illustrated in Fig. 4-19(b) will be obtained.

It is the interaction of the side-band frequencies with the carrier frequency which produces the resultant or beat frequency. Hence, in the case of 7,500-cycle modulation there are side-band frequencies of 7,500 cycles above and 7,500 cycles below that of the carrier frequency or a band width of 15,000 cycles, but the actual resultant frequency due to the interactions is 7,500 cycles. The intelligibility, therefore, is entirely due to the side-band frequencies and their reactions with the carrier and not to the carrier frequency alone.

The power contained in the side bands depends upon the variations in the amplitude of the wave. Consequently if the modulation cycle is complete, or 100 per cent, the maximum amount of power will be contained in the side band and will amount to one-third of the total power radiated.

4.16. Modulating Methods.—Modulation as it is applied to broadcast transmitters is always accomplished by means of one or more vacuum tubes. In general, one or more of these tubes are employed in the modulated amplifier (which is a linear amplifier of the carrier frequency, and the one in which the modulation actually occurs). The modulator itself is really the last stage in the audio-amplifier system and supplies the audio-frequency voltages to the modulated amplifier.

There are two general classes of modulation. The first class will be called *grid modulation* because the audio frequency is applied to the grid of the modulated amplifier.

The second class will be called *plate modulation* because the audio frequency is applied directly to the plate of the modulated amplifier and practically all the modulation occurs in that circuit. In this class there are a number of circuit arrangements possible, the principal ones being the *Heising system* and the *modified Heising system*. In the former, the plate supply to both the modulated amplifier and the modulator is obtained from a common source and is fed to them through a high-inductance, low-resistance choke coil, while in the latter system each tube has a separate plate supply and the coupling between the two plate circuits is obtained by means of an audio transformer or large condenser.

Another method of classifying modulation is to consider it to be either of the high- or low-level method. *Low-level modulation* means that it occurs in a stage preceding the final radio-frequency stage and that all succeeding stages are linear amplifiers of the modulated carrier. This method may employ either grid or plate modulation as explained above. The main advantage of this type of modulation is that the audio-frequency amplifier in the transmitter may consist of only a few low-power stages; that is, very little audio power will be required.

High-level modulation means that the last radio stage of the system is modulated. The advantage of this type is that all the preceding radio stages are pure radio-frequency amplifiers of the carrier wave, are not

necessarily linear, and may have a high gain in each stage. Grid-bias modulation when employed in the last radio stage might be considered a modified form of high-level modulation, but when used in broadcast transmitters they are put in a special class by the Federal licensing authority and as such operate under special conditions as to power rating and plate efficiency.

In the transmitter under consideration (Fig. 12-11), low-level modulation is employed in the stage succeeding the second amplifier.

4.17. The Modulated Amplifier—Push-pull System. *Grid Modulation.*—A schematic diagram for a grid-bias modulating system is given in Fig. 4-20, which is a balanced push-pull amplifier. The radio-fre-

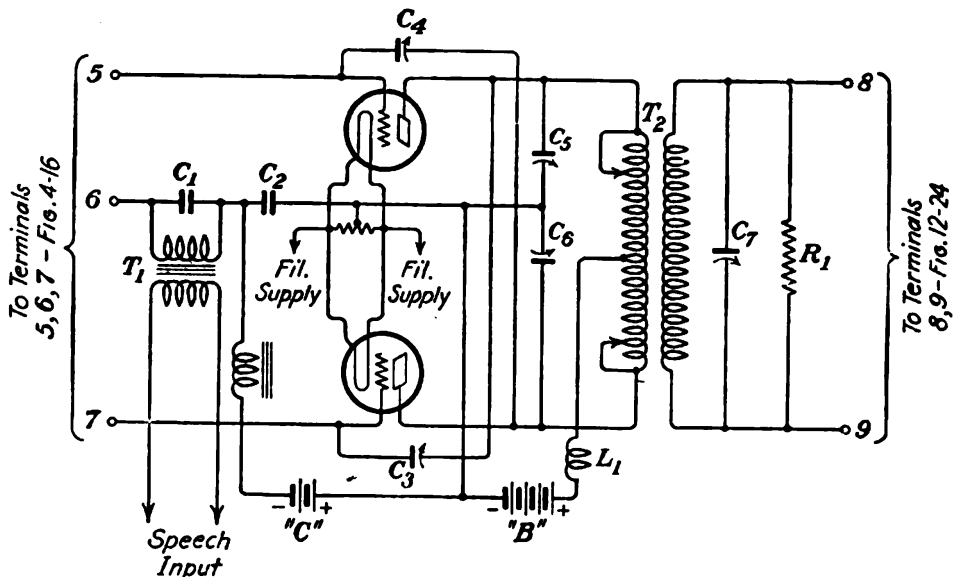


FIG. 4-20.—Circuit of push-pull type of modulated amplifier (grid modulation).

quency input to terminals 5, 6, and 7 is obtained from the preceding stage at corresponding terminals. This voltage is impressed upon the grids of the vacuum tubes out of phase; that is, when one grid is positive the other is negative and the amplified radio-frequency voltage appears across the plates similarly but in reverse order. The output of the tubes is delivered to the coupling transformer T_2 , which must be tuned to the carrier frequency by the mid-tapped condensers C_5 and C_6 . The secondary of the transformer is tuned by condenser C_7 and delivers the radio-frequency power to the load resistance R_1 and to the input of the succeeding stage, the first power amplifier. Thus far, the circuit is simply a push-pull radio-frequency amplifier, with the grid bias adjusted to the I_p cutoff point or beyond. The circuit must be neutralized or balanced to prevent self-oscillations, and this is done by means of the cross-connected balancing condensers C_3 and C_4 which, when properly adjusted, have approximately the same capacity each as the grid-plate capacity of each vacuum tube. These condensers feed back to the grids

a voltage equal to, but opposite in phase to, the voltage fed back from the plate circuit by the grid-plate capacity, thus preventing self-oscillations.

When modulation occurs in this stage, that is, when audio-frequency voltages are induced in the secondary of the audio transformer from the speech amplifier, they are impressed upon the grids in phase, both grids being either positive or negative at the same time. But this in-phase condition is the same as that previously existing as far as the grid bias is concerned, hence the audio voltages act with the grid bias, thereby making it larger or smaller depending upon which half of the cycle is effective at the particular moment. Thus the total grid bias is made to vary in accordance with the audio input, and, following the normal vacuum-tube action of grid voltage upon plate current, the plate current is made to increase when the total negative bias is low and to decrease when the bias is high. These changes of plate current produce corresponding changes in the radio-frequency output, which is the effect explained under amplitude modulation. Therefore, the audio frequency causes a change of the bias, a change of the plate current, and resulting variations of radio-frequency output corresponding to the variations in the audio-frequency input voltages—hence the term *grid-bias modulation*. One of the advantages of this system is that, although the modulated stage may be handling considerable power, very little audio-frequency power is required to modulate it.

4.18. The Heising Modulating Systems.—Figure 4-21(a) and (b) shows circuits for the Heising systems of plate modulation. In these circuits, the vacuum tube V_1 amplifies the radio frequency applied to its grid and filament from terminals 5 and 7 which are connected to correspondingly numbered terminals (the output) of the second amplifier. Condenser C_1 is a by-pass for the high frequency around the biasing potential, and C_2 is a blocking condenser to prevent short-circuiting the plate-supply battery B_1 . Condensers C_3 and C_4 tune the output transformer T_1 , the secondary of which delivers the radio-frequency power from the tube to the load resistance R_1 and the first power amplifier which is coupled to terminals 8 and 9. The tube V_1 is the modulated amplifier in the plate circuit of which the modulation occurs.

The vacuum tube V_2 is the modulator which is an audio-frequency amplifier. Speech or music from the preceding speech-amplifier system is impressed upon the input circuit of this tube by means of transformer T_1 . The amplified output is delivered to transformer T_2 the secondary of which is connected in series with the plate supply to V_1 . Inductance L_1 is a radio-frequency choke for isolating the plate-supply circuit as previously explained in the series- and parallel-feed systems. The modulator is designed to produce across the secondary of T_2 a voltage just equal to that of the plate voltage on V_1 supplied by battery B_1 , when the audio-input voltage to V_2 just reaches its maximum.

Suppose that the plate voltage on the tube V_1 [Fig. 4-21(a)] is 1,000 volts and that without modulation the peak radio-frequency current in the load resistance R_1 is 1 amp. Then, let an audio voltage be applied to the input of V_2 , of such a wave form as shown in the lower wave of Fig. 4-18. Just when the audio wave starts at point B on this curve, there is no change of plate current in V_2 , hence no voltage is built up across

the secondary of T_2 . But as the audio voltage increases to the point C on the curve, the secondary voltage of T_2 increases, finally reaching a maximum of 1,000 volts. Assume that for this half of the audio wave the secondary voltage is in series, adding

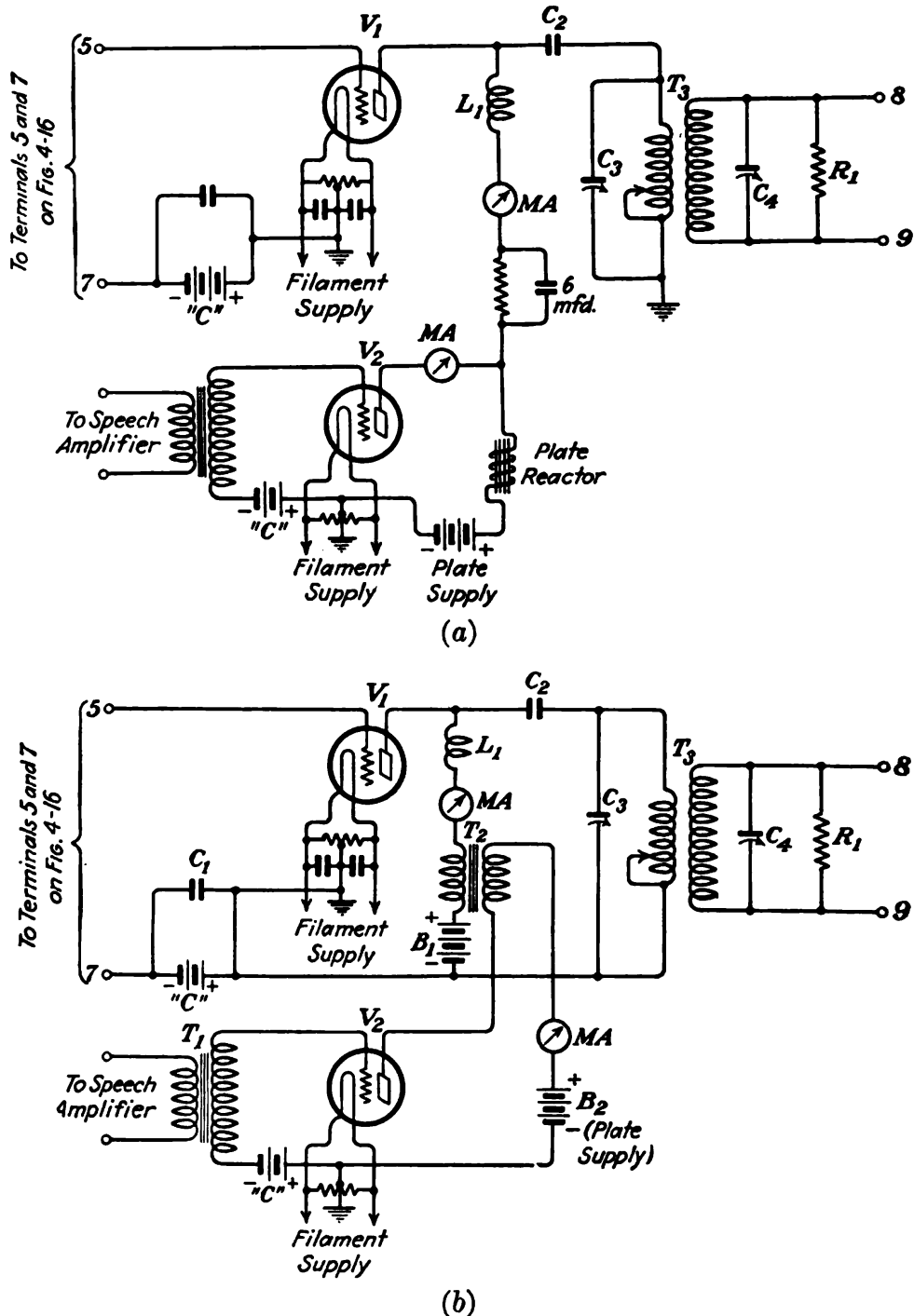


FIG. 4-21.—Heising systems of modulation: (a) modified system utilizing transformer coupling; (b) basic system utilizing reactor coupling.

to the battery potential of B_1 , that is, the upper side of the secondary is positive, thus adding to the voltage of B_1 . The total voltage on the plate of V_1 is now 2,000 volts. With double the plate voltage, the plate current doubles and the peak radio-frequency current in R_1 is doubled to 2 amp. Conversely, on the other half of the audio wave,

from D to F on the curve of Fig. 4-18, a secondary voltage will be built up in T_2 and be equal to 1,000 volts at the point E , but this voltage will be negative and will oppose that of B_1 . The plate voltage on V_1 now totals zero, hence the plate-current and radio-frequency output-current peaks will be zero. At the point F on the audio wave the voltage to V_2 is zero, there is no voltage induced in T_2 , and the tube V_1 operates normally with 1,000 volts on the plate. Thus, in passing through the entire audio cycle, the plate voltage on V_1 effectively varies from normal, up to twice normal, back to normal, down to zero, and finally back to normal, completing the cycle. Accordingly the carrier-frequency peak currents are caused to vary correspondingly, that is, the amplitude of the carrier wave is made to vary in accordance with the audio wave. This is called *amplitude modulation*.

The circuit illustrated in Fig. 4-21(b) is the basic Heising plate-modulation or constant-current system of modulation.

In this arrangement both the modulator and the modulating radio-frequency amplifier tubes V_2 and V_1 , respectively, receive their plate supply from a common source through a large choke coil or plate reactor. The successful operation of this system depends almost entirely upon the design of the reactor choke coil as may be seen from the following explanation.

Let it be assumed that a steady plate current is flowing in the respective plate circuits of V_1 and V_2 and that a radio-frequency voltage is being developed across the input terminals of the modulating radio-frequency amplifier tube V_1 . This will result in the circulation of a radio-frequency current in the plate-tank circuit in accordance with the general principles of resonance. Now since it is assumed that this radio or carrier frequency is crystal controlled, a steady current will circulate in the secondary circuit and will develop an e.m.f. across the output terminals 8 and 9, provided of course that this circuit is also adjusted to resonance with the crystal frequency.

Now if a low frequency is applied across the input of the modulator tube V_2 , it will demand an increase or decrease in the plate current of this tube depending upon the polarity of the input cycle. That is to say, if the grid of the modulator is on the positive half of the input cycle, the plate current will increase, and if on the negative half of the cycle the plate current will decrease. If, however, the plate reactor is of large inductance value, it will tend to prevent the current from increasing or decreasing through it. This action is the reason for the name *constant-current system* being applied to the Heising system of modulation. Thus it may be seen that if the positive half of the cycle, due to the low- or audio-frequency signal, demands an increase of plate current, and the plate reactor tends to prevent this change, the increase can be fulfilled only if the current in the plate circuit of the radio-frequency tube V_1 is decreased. Hence, since both plate circuits are being supplied from a common source, the plate current in the circuit of V_1 must decrease. Similarly, if the input audio-frequency cycle upon the grid of V_2 swings negative, the plate current will decrease; but the reactor will again tend to prevent this change. Consequently, the plate current in the circuit V_1 must increase.

If, therefore, an audio frequency is constantly supplied to the grid of the modulator tube, the modulation frequency developed across the plate reactor is pictured as a fluctuating voltage upon the plate of the radio-frequency tube V_1 . This fluctuation is really due to the addition and subtraction caused by the audio-frequency variation, and thereby causes the formerly steady radio-frequency current in the plate-tank circuit to be varied in its amplitude (modulation) at a rate depending upon the audio frequency of the input to the modulator tube.

The resistance in series with the plate of V_1 is provided to operate this tube at a relatively lower plate potential than that of the modulator tube so that the percentage of modulation of the carrier frequency may be very high. The condenser shunted across this resistance is necessary to allow the low-frequency variations to be applied

to the plate of the radio-frequency amplifier tube. Without this condenser the low-frequency variations would be taken up by the resistance in the form of IR -drop losses and serious distortion would result.

This discussion has been considering only 100 per cent modulation, in which the peak values of carrier current vary from zero to twice normal. Should the audio-input voltage be less than that required to produce this degree of change, then the percentage of modulation is correspondingly less. This condition is necessary, because the changes in carrier-frequency current must not only follow the different frequencies in speech or music but must also follow all the variations in amplitude of the speech or music. The modulated amplifier together with the modulator must therefore have a linear-frequency response and a linear-amplitude characteristic, and it is these features which require careful design of the modulated stage.

A linear-amplitude characteristic means that a unit change of plate voltage will cause a unit change of radio-frequency output current. If a curve were plotted for plate voltage versus output current for the modulated amplifier, with the radio input to this stage held constant, the curve should be practically a straight line. This type of curve is called a *dynamic* characteristic of the vacuum tube. In the development of a radio transmitter many such curves are plotted in order to determine the necessary voltages and output impedance to produce this desired straight characteristic.

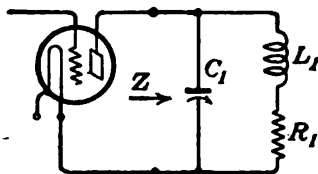


FIG. 4-22.—Simplified amplifier circuit with all battery and input circuits removed.

4.19. The Output Impedance of the Modulated Amplifier.—Output impedance is a very important factor in determining the operation of the modulated amplifier. By output impedance is meant the absolute impedance of the output circuit at the operating frequency, as viewed

from the plate and filament of the vacuum tube. Figure 4-22 shows a simplified amplifier circuit with all battery and input circuits removed.

When the output circuit, which consists of C_1 , L_1 , and R_1 , is tuned to the operating frequency of the amplifier, the capacitive reactance of the condenser C_1 practically equals the inductive reactance of the coil L_1 . The total reactance around in this circuit is practically zero. The smaller the value of R_1 , the more nearly equal will be the two reactances. This condition is obtained by varying the tuning condenser C_1 , until the plate current of the vacuum tube dips down to its lowest value. During the tuning process the minimum plate current occurs when maximum impedance is obtained in the output circuit, and this condition exists when resonance occurs. That is, minimum plate current, maximum impedance, and series resonance all occur at about the same setting of C_1 . Under this condition, the impedance of the output circuit, indicated in Fig. 4-22 by the symbol Z with the arrow pointing in the direction of the

output circuit under consideration, is approximately

$$Z = \frac{X_L^2}{R} \quad (5)$$

where X_L is the inductive reactance of L_1 , and R is the total resistance of the circuit including R_1 .

For example, if the inductance of L_1 is 152 μ h and the operating frequency is 1,050 kilocycles, and the resistance of the coil and R_1 is 50 ohms, calculations are as follows:

$$X_L = 2\pi fL = 2 \times 3.14 \times 1,050 \times 152 \times 10^{-6}$$

$$X_L = 1,000 \text{ ohms}$$

Therefore,

$$Z = \frac{X_L^2}{R} = \frac{1,000^2}{50} = 20,000 \text{ ohms}$$

If it is desired to make this impedance match the plate resistance of the tube, either the number of turns on the coil are changed, thus changing the upper term of the impedance equation, or the resistance R_1 is adjusted to vary the lower term of the equation. If the coil turns are increased the impedance increases, and if the resistance is increased the impedance decreases.

The output circuits employed in the various amplifiers of the radio transmitter of Fig. 4-1(c) are not simple single coils but coupling transformers. Figure 4-23 illustrates such a circuit. The transformer consists of the primary L_1 and the secondary L_2 , with the mutual inductance between them represented by the symbol M . The primary is tuned by condenser C_1 , while the secondary is tuned to series resonance by condenser C_2 .

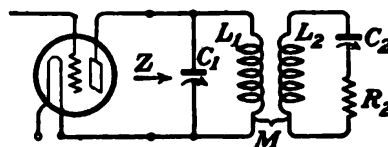


FIG. 4-23.—Amplified coupled to its load through a coupling transformer.

R_2 is the load resistance in which the radio-frequency power is dissipated.

With the circuits tuned as indicated above, the entire secondary circuit may be reduced to the equivalent shown in Fig. 4-22. It is possible theoretically to replace the secondary circuit with its load resistance R_2 by the primary inductance L_1 and an equivalent resistance R_1 in series with it. This method of dealing with the complex transformer is used merely to simplify the calculations of impedance and other functions, and the process of theoretically substituting the equivalent resistance R_1 for the true load resistance R_2 is called *reflecting the resistance* into the primary circuit. What actually happens is that, owing to the action of the transformer, the current flowing through R_2 is of such a value as to cause a voltage to be induced back into the primary circuit, of such value and phase angle that this reinduced voltage is equivalent to the voltage drop which would occur in a resistance of the proper value if it really

were there. The numerical value of the reflected resistance is equal to

$$R_1 = \frac{X_M^2}{R_2}$$

where X_M is the mutual reactance of the primary and secondary of the transformer, and R_2 is the load resistance (the resistance of L_2 is assumed to be very small and is neglected here).

To calculate the impedance of the new equivalent circuit, the same procedure and formulas are used as for Fig. 4-22, except that the lower term in the impedance formula is now the reflected resistance, plus the coil resistance of L_1 .

In the radio transmitter of Fig. 4-1(c) the buffer amplifier employs a fixed tuned transformer, so its impedance is not adjustable. The second amplifier transformer is adjusted to obtain a relatively high impedance for voltage and power amplification by keeping the inductance large and the reflected resistance small. In the modulated stage the output impedance is adjusted to obtain linear amplification as explained in Sec. 3.13. This impedance may be found to be necessarily equal to the plate resistance of the tube, or some value greater than that, up to twice the plate resistance.

4.20. The first and second power amplifiers, as their names imply, are purely power amplifiers designed to bring the power level of the output of the modulated amplifier up to the value required for the maximum rated output of the radio transmitter. The circuits for these stages may be of general form shown in Fig. 4-20, except that the speech-input transformer T_1 would be eliminated. Each of these stages handles the modulated carrier and, therefore, must be just as carefully tuned and adjusted for proper output impedance as the modulated stage.

4.21. Power-amplifier Grid Excitation.—The calculation of the proper amount of grid excitation necessary to drive a power-amplifier tube efficiently is a rather involved procedure since it must take into account the type of tube used and the load impedance into which the power-amplifier tube must function. Various values of grid excitation may be used for a given tube, depending upon the particular value of load impedance required, to develop a given amount of power across the load impedance. *A fairly accurate ratio of the power output necessary in the driver tube to excite properly a power-amplifier tube is that the excitation be approximately 10 per cent of the amplifier-power output required.* That is, if a power-amplifier tube is to deliver 500 watts into its load circuit, it must receive a grid-excitation power of approximately 10 per cent of this value, or 50 watts. Thus the driver tube must be capable of delivering to the grid of the power-amplifier tube at least 50 watts for proper grid excitation.

Although this ratio is fairly accurate in general practice, a more precise method would be to calculate the input grid voltages, plot a graph for different values of load impedances, and note the various output effects as to linearity and power until the desired combination is obtained.

In the power amplifier illustrated in Fig. 4-28 the proper value of grid excitation is regulated by the shunt resistances connected between the grids and filament center of the two power-amplifier tubes.

If the two power tubes are to deliver an output of 500 watts to the load circuit, the input power supplied to the grids is generally 50 watts. The resistance may then be regulated until the desired input drive is obtained, as will be explained later.

Another method of determining the grid-excitation voltage or power input necessary is to place two radio-frequency ammeters in the tank circuit of the driver tube. If these two meters show identical values, the voltage

$$E_g = IZ_L \quad (6)$$

This arrangement is illustrated in Fig. 4-24.

Another simple method of determining grid excitation is illustrated in Fig. 4-25, in which the grid-excitation voltage E_g is determined by the product of the current flow, as indicated by the radio-frequency ammeter M , and by the reactance of the condenser C_1 .

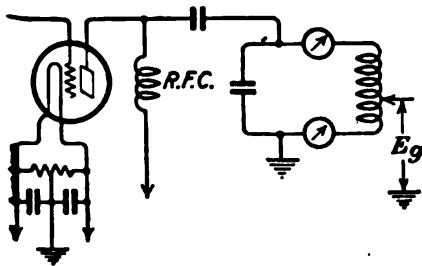


FIG. 4-24.—Radio-frequency ammeters in tank circuit to determine grid excitation necessary.

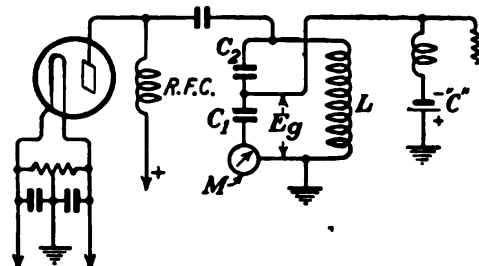


FIG. 4-25.—One radio-frequency ammeter M determines grid excitation in this circuit.

For example, assuming that the tank circuit L, C_1, C_2 , has been adjusted to resonance as indicated by the meter M at a frequency of say, 1,650 kilocycles, and the condenser has a capacity of 0.006 mf. at this adjustment, the reactance

$$X_c = \frac{1,000,000}{2\pi fC} = 16 \text{ ohms}$$

If the meter M reads 5 amp., then

$$E_g = IX_c = 5 \times 16 = 80 \text{ volts}$$

Perhaps the simplest and most accurate method is that illustrated in Fig. 4-28 which is a modification of the arrangement used in the transmitter, Fig. 12-11. The power is developed in the load resistor R . Let us assume that this power must be sufficient to drive two 1-kw. tubes such as the Western Electric 279A type, the unmodulated or carrier frequency of which delivers an output of 1 kw. into the load circuit L_3, C_3 . These particular tubes are rated at 1 kw. but are capable of a peak load as high as 2 kw. without overloading. That is to say, if the carrier is

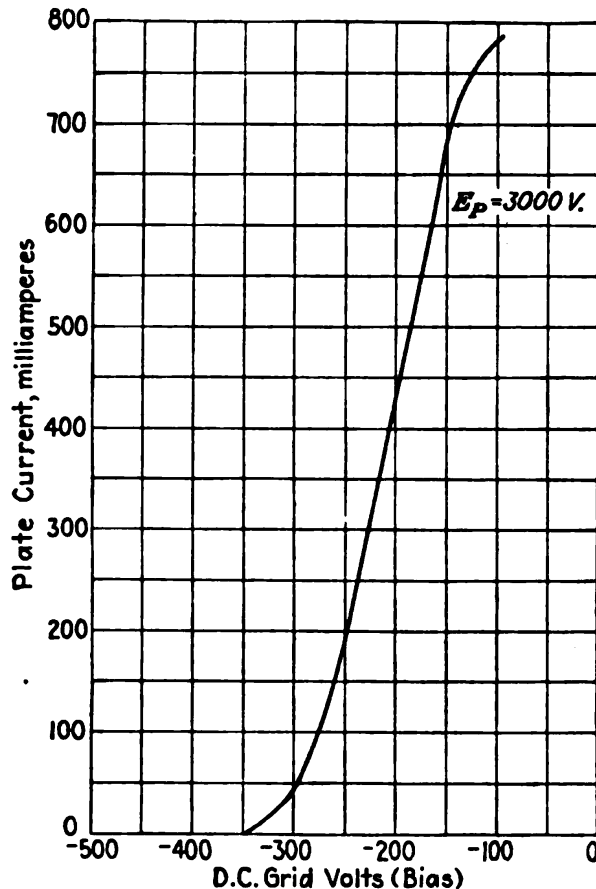


FIG. 4-26.—Static characteristic curve of W.E. 279-A vacuum tube. (Courtesy of Western Electric Company.)

adjusted to 1,000 watts of power, each tube delivers approximately 500 watts of power in a push-pull arrangement as shown. Since the modulated peak power will be four times the carrier power at 100 per cent modulation, or 4,000 watts, these tubes must be and are capable of accommodating these swings without overloading.

However, in the adjustment of the transmitter the excitation power and the output power are based upon the carrier or unmodulated power to be used, which in this circuit is 1,000 watts.

Before calculating the necessary drive let us examine the characteristic curves of this particular tube (Western Electric 279A) to ascertain the proper operating condition. Figure 4-26 illustrates the *static* I_p - E_p ,

characteristic curve at the normal-operating plate potential of 3,000 volts and a bias potential of 275 volts. Figure 4-27 illustrates a dynamic characteristic curve which shows the amount of power that can be obtained in the load circuit with and without the flow of grid current.

It is important in any power amplifier to maintain the grid-current flow as close to zero as possible because, if the modulated radio-frequency peak voltages applied to the grid of the power tubes exceed the value of the grid bias, a grid current will flow during the applied positive peaks. This may result in serious audio-frequency distortion owing to the fact that the grid-current flow will be 180 degrees out of phase with the plate current. In view of the fact, however, that, at the 100 per cent modulation in the usual program transmission, only occasional peaks reach the high-per-

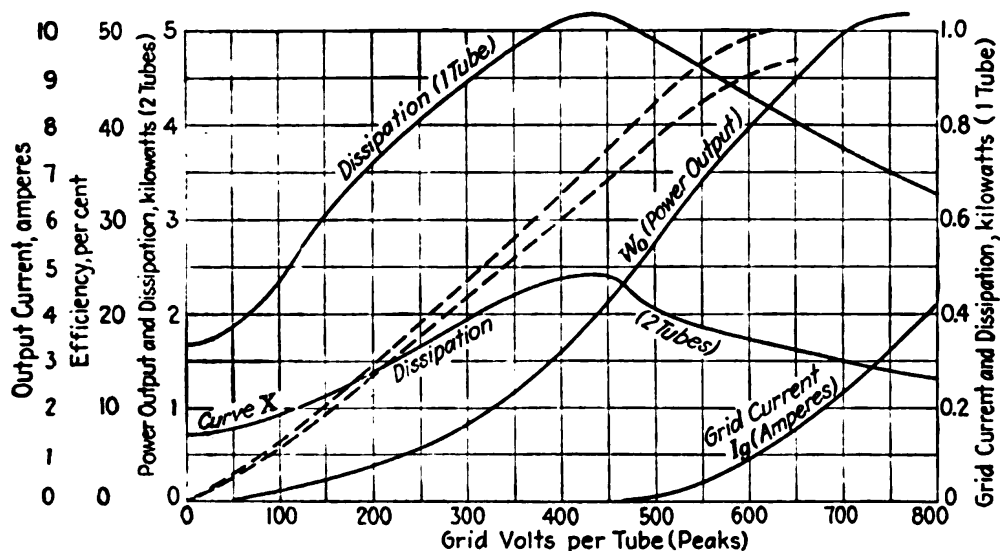


FIG. 4-27.—Dynamic characteristic curves of two W.E. 279A vacuum tubes in push-pull operation. Curve X by the authors. (Courtesy of Western Electric Company.)

centage point, the positive grid current may go as high as 0.2 ma. without noticeable audio-frequency distortion. As a matter of fact, a very slight flow of grid current during the positive intervals of complete modulation will tend to increase the plate efficiency of the tube and consequently enable it to handle more power.

It is a very simple matter to determine if the grid current is excessive by inserting a direct-current ammeter or milliammeter in the tube plate circuit. If, during modulation, the meter fluctuates excessively, it is probable that the amplifier is distorting. In other words, an excessive grid current acts as a load upon the plate current and, owing to its 180-degree phase difference, alters the true shape of the plate-circuit component. This condition may be due to excessive grid excitation, improper plate and grid-bias voltages, or improper load-impedance relations.

Now let us examine the 279A tube *dynamic* characteristic for a specified frequency and load impedance, and ascertain what value of grid-excitation voltage will be necessary to excite it properly with a minimum of grid-current flow and a maximum power output. Figure 4-27 illustrates the approximate characteristics for this tube at the rated voltages when functioning into a load impedance of about 3,500 ohms.

In a balanced or push-pull linear amplifier the tuned-load impedance due to L_3C_3 (Fig. 4-28) is adjusted to four times the value of the plate resistance of a single tube in order that each tube will function into an impedance at least equal to its own value so that the proper power dissipation into the load will be obtained (see formula 5).

The top dashed curve in Fig. 4-27 illustrates the approximate efficiency of the tubes with relation to the excitation voltage, and the lower dashed curve shows the value of the tank power in the load circuit L_3C_3 . It will be noted that the two curves are practically linear over a grid-excitation voltage ranging from 0 to approximately 650 volts. These curves assume a frequency of 1,000 kilocycles and a load impedance of 3,400 ohms.

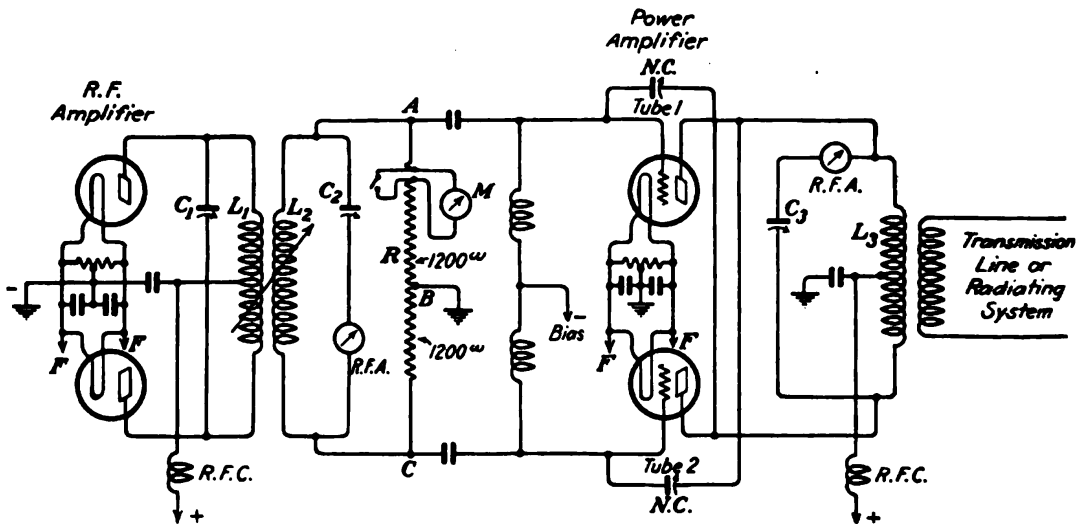


FIG. 4-28.—Balanced or push-pull linear amplifier.

Now, if the tubes are biased almost to the point of plate-current cut-off (class B), which in this circuit is produced by a negative bias of approximately 275 volts on the grid at a plate potential of slightly over 3,000 volts, there will be produced in the plate load circuit a power output representing the square of the input-grid voltage. The peak output will be four times greater than the unmodulated carrier power when 100 per cent modulation occurs. The proper value of grid-excitation voltage must, therefore, be determined in order that the unmodulated carrier-frequency power in the plate load circuit will be 1,000 watts. Consequently each tube must deliver 500 watts into the load circuit.

To accomplish this, grid excitation of about 265 volts must be applied to each tube, or, in other words, a potential of 530 volts across the two grids at the points A and C of the excitation resistance R in Fig. 4-28.

To develop an e.m.f. of approximately 530 volts across R , the entire resistance must dissipate 100 watts. To adjust for this, a radio-frequency ammeter M is connected in series with the resistance R and the radio-frequency drive varied until the meter reads a value of current which, when multiplied by the resistance, will equal about 530 volts. An indication of about 0.22 amp. will develop 100 watts in the 2,400

ohms resistance. Thus

$$I = E/R = 530/2400 = 0.22 \text{ ampere}$$
$$W = I^2R = 116 \text{ watts}$$

which is close enough to the required value.

All these calculations are based upon the unmodulated carrier frequency and a load impedance of approximately 14,000 ohms looking into L_2C_2 at the assigned operating frequency. At 100 per cent modulation the peaks developed in the load circuit will be 4 kw. of modulated power or 2 kw. per tube. The plate power dissipation accompanying this value of load dissipation is readily accommodated by these tubes since it occurs only during occasional peaks. It is extremely important that this load impedance be correct for the type of tube used, not only for the proper development of power, but also for the ability of the tube to deliver a linear characteristic across the load. It will be remembered that if the load impedance is too high, the insufficient development of power across it will cause the modulation percentage to be too low. This would result in a downward deflection of the output radio-frequency ammeter during modulation. If, on the other hand, the load impedance is too low, an excessive proportion of the power developed will be dissipated in the tube and not in the load, thereby causing an overheating and overloading of the tube itself. In addition, the modulation percentage due to the low load impedance may be too high and consequently may produce serious audio-frequency distortion.

4.22. High-efficiency (Doherty) Power Amplifier.—It is a fundamental characteristic of vacuum-tube power amplifiers that the maximum efficiency is obtained only when the tube is delivering the maximum possible radio-frequency voltage to its load. Since the maximum possible voltage is delivered only on occasional momentary modulation peaks, the normal or carrier voltage being only one half of the maximum value, the average or all-day efficiency of such amplifiers is only about 33 per cent.

The Doherty high-efficiency circuit has provided the solution to this difficulty through the use of a new principle, whereby the normal or carrier power is delivered at high radio-frequency voltage, and hence high efficiency, by one tube alone, and the additional voltage required for modulation peaks is supplied by a second tube when needed.

If we consider an electric power system in which a generator G_1 is delivering power to a load at its maximum voltage, and more voltage is found to be required, the additional voltage could be obtained by connecting an additional generator G_2 in series with the first, as shown in (a) Fig. 4-29. However, vacuum tubes cannot be operated in series in this manner. Nevertheless the Doherty circuit permits the equivalent operation to be achieved. The basis of this operation, and the Doherty

circuit, is the discovery that, by the use of simple coupling networks placed in the circuit as shown by N_1 and N_2 in (b) Fig. 4-29, the tubes may be made to give the effect of a series connection even though they are operating in parallel into their common load. Tube 1 can then operate alone at high efficiency for the carrier output, while tube 2 contributes the necessary additional power for the positive swings of modulation.

As with any amplifier regardless of type, the load impedance for the Doherty amplifier is adjusted to the proper value with a radio-frequency bridge. The amplifier is then tuned, with power applied, by adjusting three variable condensers from the front panel. These three controls are independent, and the entire adjustment can be very quickly made and checked in a few minutes. This adjustment is done with the aid of a cathode-ray oscilloscope, the best possible means of checking the tuning of any type of amplifier, because it is the only positive means of indicating phase relations.

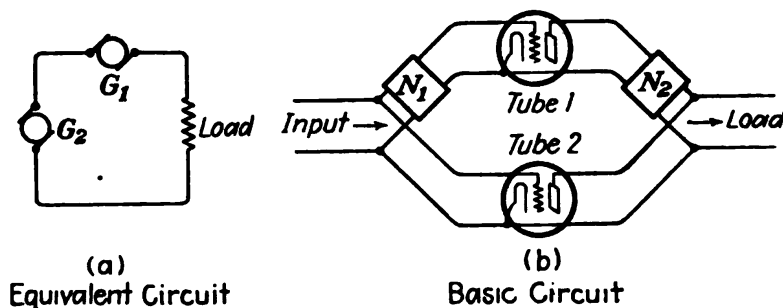


FIG. 4-29.—Doherty amplifier illustrative circuits.

The Doherty circuit reduces the power consumption of linear power amplifiers by a factor of two and reduces the plate dissipation by a factor of three. Unlike high-level modulation, the Doherty circuit does not require additional tubes as high-power modulators, nor does it subject the radio-frequency amplifier tubes to excessive plate potentials, since the plate voltage is held constant. This circuit also permits operation with zero carrier shift, giving maximum signal coverage. Since 1938, the Doherty circuit has been incorporated in every 1-, 5-, and 50-kw. broadcast transmitter manufactured by the Western Electric Company.

It will be useful at this point to examine the structure and properties of the impedance-inverting networks [N_1 and N_2 , Fig. 4-29(b)] which are the heart of the Doherty circuit.

*Impedance-inverting Networks.*¹—In Fig. 4-30 are shown two networks having the interesting and easily verified property that a voltage E applied or appearing at either end of the network is associated with a coexisting current at the other end having an amplitude E/X and a phase differing by 90 degrees from the phase of E . This cur-

¹ This section and the sections that follow on the Input Circuit and Efficiency are from the paper entitled "A New High Efficiency Power Amplifier for Modulated Waves," by W. H. Doherty of the Bell Telephone Laboratories.

rent is independent, in amplitude and phase, of the nature of the impedance through which it flows at the terminals of the network. When this terminating impedance is a resistance R_1 and a voltage E is applied across the other terminals, the above property leads immediately to the following relation:

a. The voltage phase retardation introduced by the network is 90 degrees regardless of the value of R_1 ; this indicates that no phase modulation will be occasioned by the variation in terminating impedance of the network when the second tube comes into action.

b. The input impedance of the network is a resistance inversely proportional to R_1 ; it is equal to X^2/R_1 .

c. The voltage across R_1 due to E is proportional to R_1 ; it is equal to $-jE \times R_1/X$.

The above properties are likewise possessed by a quarter-wave transmission line whose characteristic impedance is X ohms and by certain other network configurations.

If the coils in the above networks are replaced by condensers and the condensers by coils, the same properties hold except that the phase is advanced 90 degrees instead of retarded.

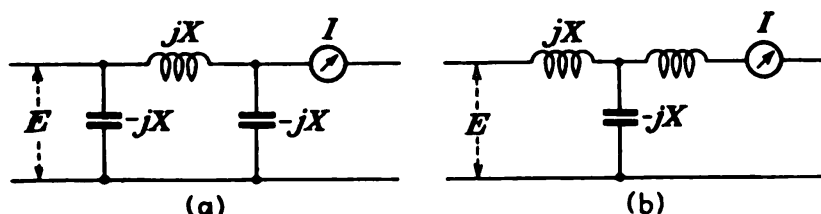


FIG. 4-30.—Typical impedance-inverting networks.

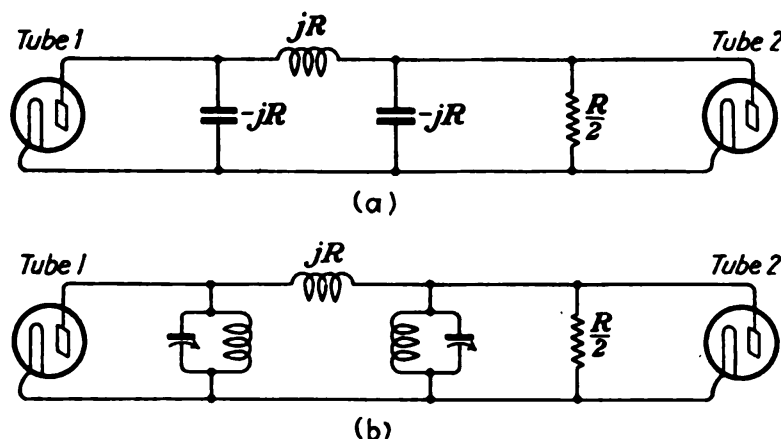


FIG. 4-31.—Evolution of the input circuit.

By using the π network of Fig. 4-30(a), a very simple output circuit for the amplifier may be arrived at. The fundamental relations are shown in Fig. 4-31(a). A load circuit is designed having a shunt resistance of $R/2$ ohms, as if the two tubes were to be connected directly in parallel. R , as before, is the impedance into which each tube is to work when delivering its peak power. The 90-degree network is then interposed between tube 1 and this load circuit. The constants of this network must be such that when tube 2 is inactive (that is, when the network is terminated in $R/2$ ohms) the alternating voltage across No. 2 is half the voltage across No. 1, so that if the voltage on No. 1 has reached the maximum permissible value when the carrier power is being delivered, the voltage on No. 2 will have reached only half this value and may therefore rise sufficiently to accommodate the peaks of modulation. This relation requires that the three elements of the 90-degree network should have reactances of R ohms.

Next it is desirable, as in any radio-frequency power amplifier, to connect across each tube an antiresonant circuit to provide a path of fairly low impedance for the harmonic components of the radio-frequency plate currents. By detuning these antiresonant circuits sufficiently to obtain negative shunt reactances of R ohms, the shunt condensers of the 90-degree network may be eliminated, and the complete output circuit is reduced to the simple form shown in Fig. 4-31(b).

The effective shunt load $R/2$ would in most cases be obtained by coupling the antenna circuit to the necessary extent into the tuned circuit across tube 2. The intertube coupling coil designated jR may be used to carry the direct-current plate current from one tube to the other, so that only one plate choke is necessary.

The process of tuning the circuit is very simple. The proper reactance for the intertube coupling coil having been selected and the load having been coupled in so as to obtain the proper shunt resistance $R/2$, the condenser across tube 2 is adjusted under power to give a 90-degree phase relation between the plate potentials on the two tubes, as indicated on a cathode-ray oscilloscope by an elliptical pattern with axes at right angles. The condenser across tube 1 is then adjusted for minimum plate current on this tube, in accordance with the usual method of tuning a power amplifier, and the plate-circuit tuning is complete.

An interesting feature of this circuit is that when the carrier is unmodulated the radio-frequency harmonic output is considerably reduced because the power is coming entirely from tube 1 and the harmonics generated in this tube are attenuated by the intertube coupling circuit.

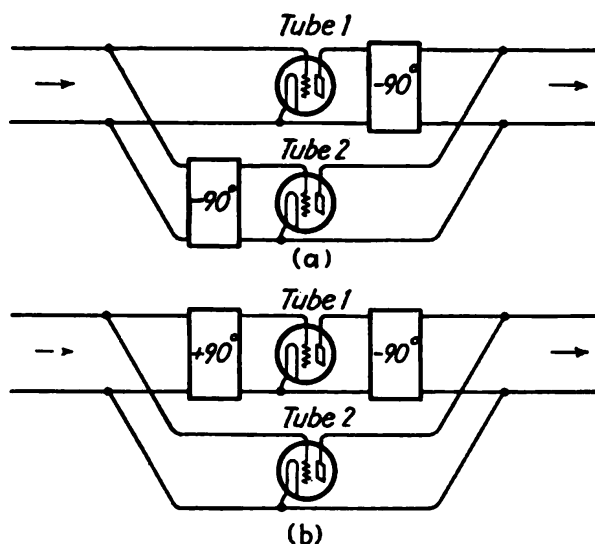


FIG. 4-32.—Alternative arrangements of grid phase-shifting networks.

The Input Circuit.—The high-efficiency system being described is unique in being purely a method of amplification and not a modulation scheme and, therefore, requiring only a modulated wave from a lower powered transmitter for exciting the grids. In applying this modulated input to the amplifier, it is necessary to have the voltages on the two grids 90 degrees apart in phase in order that each may be opposite in phase to the related plate potential, as is necessary in any power amplifier.

The 90-degree phase relation may be obtained by using a network of the general type shown in Fig. 4-30, and the adjustment is accomplished under power, using a cathode-ray tube, in the same way as has been described for the plate circuit.

With the appropriate 90-degree network in the grid circuit, the amplifier assumes one of the forms indicated in Fig. 4-32. This figure illustrates clearly the fundamental simplicity of the new system. Obviously the operation is essentially the same as that

of the conventional linear amplifier at any time that the load is equally divided between the tubes, as is the case for an instant at the peak of a completely modulated wave; but merely by the introduction of two phase shifts, it becomes possible to make use of a variable load distribution to establish the necessary conditions for high efficiency at outputs much smaller than the peak output.

The simplest and most obvious way of keeping the second tube inactive until the carrier point is reached is by the use of a higher grid bias on this tube, with sufficient excitation so that at the peak of modulation the required output is obtained from the tube in spite of the higher bias.

The first tube, being biased nearly to cutoff, behaves like a conventional linear amplifier from zero excitation up to the carrier point. Beyond this point, because of the changing load impedance, the excitation is not required to rise to twice its carrier value. In most of the tests, it has been found that the effective excitation on the first tube is required to rise only about 40 per cent instead of 100 per cent on the positive half of the modulation cycles. A further increase in drive would carry the instantaneous grid potential up to a point where too many of the electrons would go to the grid instead of the plate, causing a very rapid increase in positive grid current. A number of ways immediately suggest themselves for obtaining the required limiting action; one of the simplest ways is by the use of a grid leak in the bias supply to the first tube; another useful method is to permit the grid current to limit the drive by its shunting effect on the exciting circuit. In Fig. 4-33, the

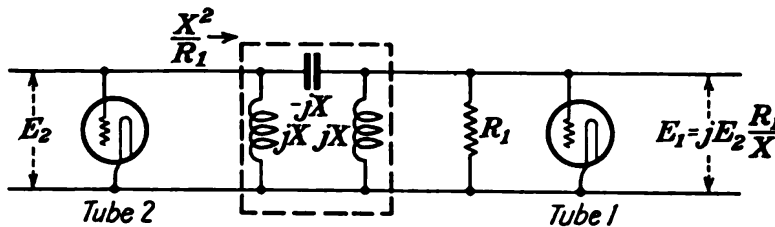


FIG. 4-33.—Grid exciting circuit.

two grids are shown connected to a phase-shifting network consisting of reactances of X ohms and a resistance R_1 . When the grid of tube 1 is not conducting, the voltage E_1 obtained on this grid with a voltage E_2 applied to the network is $jE_2 \cdot R_1/X$. When grid current flows in tube 1, the effective reduction in R_1 causes a diminution in the ratio of E_1 to E_2 . The proper value of R_1 to give the desired limiting effect is easily calculated from the approximate maximum grid current. The proper resistance is not at all critical because of the rapidity with which the grid current increases with drive at power outputs close to the maximum. This value of R_1 is considerably higher (that is, the required driving power E_1^2/R_1 is lower) than in the case of the conventional linear amplifier, where R_1 must be made low enough so that the grid current will not cause appreciable diminution in the drive.

As R_1 is effectively lowered by the rapidly increasing grid conductance, the input impedance X^2/R_1 of the grid phase-shifting network is increased, compensating to a large extent for the shunting effect of the grid current which flows in tube 2 as it approaches its peak output, so that the driving stage is assisted in maintaining the proper drive on No. 2.

On account of these effects, the grid driving power required for this type of amplifier is actually less than for the conventional linear amplifier, and in the experimental work a driving stage has been used in most cases having only about half the power capacity customarily employed for exciting a conventional amplifier of the same output.

Efficiency.—The efficiency of the final stage (of the experimental circuit) with its output circuits was 60 per cent with the carrier unmodulated and 63 per cent at 100 per cent modulation. This high efficiency of the final stage, together with the reduced grid driving power permitted by the new system, resulted in a reduction in the total power consumption of a 50-kw. transmitter, including all auxiliaries, from about 230 kw., required by the conventional type, to approximately 135 kw. in the new (high-efficiency) system with normal program modulation. It is interesting to note that the total power input in this case is actually less than the power dissipated in the water-cooling system in the usual 50-kw. installation.

4.23. The Audio Monitor.—The purpose of the audio monitor connected to the output circuit of the second power amplifier in a broadcast transmitter is to demodulate a small portion of the radio-frequency power in the last stage of the transmitter. It then delivers the resultant speech or music to a loud-speaker, the input of which may easily be switched from the output of the monitor to the input of the speech-amplifier system, thus permitting a comparison of the quality of the program going into the radio transmitter with the program after modulation. Thus a constant check is available on the overall operation of the transmitter. Therefore, if the input quality of the program is satisfactory, and the output of the monitor sounds poorly, it is an indication that some part of the transmitter is out of order and a thorough check should be started at once to locate the difficulty.

4.24. The Frequency Monitor.—The purpose of the frequency monitor is to give the transmitter operator a constant check on the frequency of the emitted wave. This unit is connected to a very low voltage source in the output circuit and requires practically no carrier power from the transmitter. It is usually in continuous operation and requires very little attention other than to check the carrier frequency of the transmitter at regular intervals. Should the carrier show an appreciable deviation, such, for example, as 40 cycles, and a careful check indicates that the deviation is not in the frequency monitor itself, the carrier frequency may be corrected by adjusting the small trimmer condenser previously referred to as being across the quartz plate.

The operation of the frequency monitor is described in detail in Chap. 12 on Broadcast Transmitters.

4.25. Antenna Coupling Circuits.—The method of coupling an intermediate-wave broadcast transmitter to the antenna is generally somewhat different from the methods used in short-wave transmitters, which will be described in the chapter on Antennas. It is more common to use direct coupling to the antenna in small intermediate-wave installations, as the losses due to the transmitter building being in the field of the antenna are not so serious as they would be on a short-wave transmitter. The circuit shown in Fig. 4-34 is a very common type of inductive coupling for broadcast frequencies. The circuit shown in Fig. 4-35 has the advantage of greatly reducing all harmonics in the output owing to the low reactance of the coupling condenser, C_2 , to higher harmonic frequencies, and to the by-passing effect of the grounded *Faraday shield*.

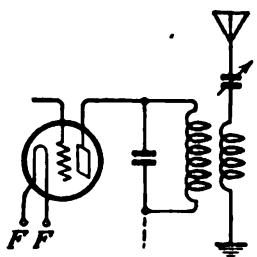


FIG. 4-34.—Inductive coupling for broadcast and intermediate frequencies.

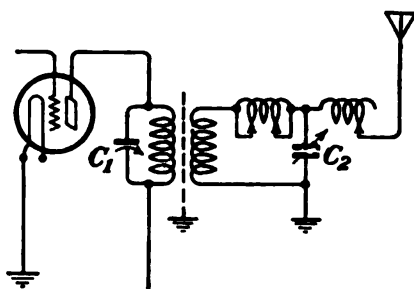


FIG. 4-35.—Harmonic reducing inductive coupling for broadcast and intermediate frequencies.

The transmission line connecting the transmitter with a remote antenna is used in high-power installation where it is desired to place the transmitter building out of the antenna field. The transmission line and the radiating system will be explained in Chap. 7 on Antennas.

4.26. Meters.—In all diagrams and discussions given, there has been no mention made of the location, number, or types of meters to be employed in the various circuits. In some circuits, meters are always included, while in others only those absolutely essential are provided. It is of course desirable to have instruments in each circuit to assist in tuning the transmitter, to check, by means of current and voltage readings, all circuits during operation, and finally as a rapid method of locating trouble, should any occur. In general, the vacuum-tube oscillator requires a plate-current and grid-current meter. The buffer and second amplifier require only a plate-current meter, except in critical cases where excessive grid current may injure a tube. The modulator requires both grid- and plate-current instruments, to serve as a rough check on operation and distortion of the audio frequencies. All the remaining radio stages require grid- and plate-current meters and also thermocouple ammeters in the output circuits.

The last radio stage must have plate-current and plate-voltage meters and an antenna ammeter of an accuracy accepted by the Federal licensing

authority. These instruments must be provided to permit checking the operating efficiency and output power of the radio transmitter. When a transmission line is used, a thermocouple ammeter is connected in the antenna lead and another instrument consisting of an external thermocouple and ammeter is connected in the ground lead. Two wires are connected to the external thermocouple and brought through a conduit to the transmitter building where connection is made to the indicating meter. Thus the thermocouple is located in the coupling unit, and the meter itself is located in the transmitter building, probably on one of the panels of the transmitter, thus providing a means of constantly checking the current in the antenna-ground system by remote means.

4.27. The Power Supply.—Radio transmitters are classed, in regard to operating power, as being either direct-current operated or all-alternating-current operated. Ultimately the power source is generally alternating current, except on shipboard, and the difference of operation merely lies in the type of power-converting equipment used.

A transmitter which employs direct current throughout for filament, bias, and plate supplies may be said to be direct-current operated, while if the filament supply is alternating current, operating heater-type tubes, or mid-tapped filament transformers and resistors, and if plate- and grid-bias voltages are supplied by a rectifier, the transmitter is classed as being all-alternating-current operated. It is also possible to operate the filaments on alternating current and to use a direct-current power source for bias and plate power. When this is done, the transmitter is not considered as being *all-alternating-current* operated.

The Filament Supply.—On direct-current-operated transmitters the filament supply is obtained from a direct-current generator usually driven by an alternating-current motor. On transmitters using alternating-current tubes, the filament power is obtained direct from the power lines through a step-down transformer. This transformer may have a common primary and several secondaries with different voltages available, or the several secondaries may be for the purpose of isolating certain tubes. A common secondary for all tubes may be used instead of separate secondaries if desired. As transformers require no maintenance, this method of providing filament power has some advantages over direct-current generator systems.

The Plate Supply.—To keep down extraneous noises and hums in the output of tubes, it is necessary to have a practically pure supply of direct current. This may be supplied either by motor-generator systems or by some type of rectifier. Both of these types of power supply are explained in later chapters (see Chaps. 6 and 17).

4.28. Harmonics and Their Causes.—Harmonics in tube plate circuits are generally due to distortion of the plate-current wave shapes in

the power stage of a radio-frequency amplifier. This is primarily due to the fact that, when an amplifier receives large grid-excitation voltages, the plate current is driven into the upper curved portion of the characteristic curve. If, therefore, a radio-frequency power-amplifier stage is adjusted to the point at which the grid-excitation voltage is maintained so that the plate-current rise does not extend into the upper curved area, the harmonic generation may be practically eliminated. Unfortunately, however, if the grid-excitation voltage due to the carrier frequency is maintained at these limits, no assurance can be given that the same condition will prevail when the carrier is modulated; not unless the modulation percentage is extremely small, and then the output-power efficiency is so low that operation would be impractical.

In order to increase efficiency, therefore, the grid bias (E_c) is greatly increased to, or nearly to, the point of plate-current cutoff when using class B amplification. When using class C amplification this bias is increased to from one and one-half to twice the cutoff value, and sometimes more. The grid-excitation voltage (E_g) may then be greatly increased to swing far up on the straight portion of the curve. In doing this, the plate-current component resembles approximately a half-wave sine curve with its associated harmonic-current components.

Current and voltage relations in a tube circuit, using a high grid bias for transmitting, affect harmonic generation. When the grid-excitation voltage is low, the plate current practically follows the grid-excitation voltage wave form. This is particularly true if the tube possesses a high amplification factor because then the plate reactionary effects are very small.

If, on the other hand, however, the grid excitation is increased, the plate current will dip due to the decrease in plate potential below the grid-excitation voltage. This may be clearly seen by a careful examination of Fig. 4-36 in which the grid-excitation voltages are of varied values such as occur during the process of modulation. Harmonics are produced when a dip occurs in a plate-current peak.

It will be noted that during the intervals of low grid-excitation voltages the harmonic content will be very small, and that during the period of high grid-excitation voltages the harmonic content will be greatly increased. Hence, since the grid voltage is a function of the degree of modulation, the resultant harmonic content will depend upon the average effect between the low- and high-voltage grid swings. In other words, although a transmitter is said to be modulated at 100 per cent, in reality these peaks are only of short duration and it is not to be understood that 100 per cent modulation means that all peaks are of that value. This means then that the actual percentage of modulation is really the *average* between the low and high peaks during the usual radio program. Hence, the average percentage of modulation during pro-

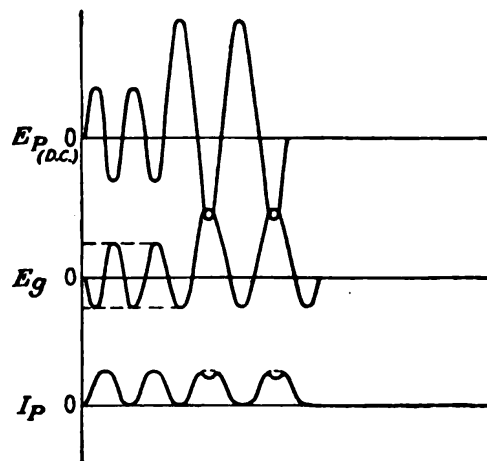


FIG. 4-36.—Current and voltage relations in a vacuum-tube circuit.

gram transmission may be considered as being of a low value, although it is desirable that occasional peaks should reach the full 100 per cent point. It is the effect of these occasional peaks reaching 100 per cent which classifies a transmitter as being modulated at this percentage, and not the average degree of modulation which may be lower in percentage. Actually, if every peak during a program were to swing the grid to the point of 100 per cent modulation, serious distortion, due to harmonic generation, would result.

Thus it may readily be seen then that by the proper design of tubes and load impedances, together with the proper value of bias and plate voltages, the average harmonic content may be reduced sufficiently to avoid distortion. Practically, this may be accomplished by reducing the plate-voltage component almost to the point in which the plate-current dip begins, as illustrated by the dotted lines on the I_p curves in the figure.

Thus it may be seen that the harmonics generated in tube circuits, due to the distortion of the wave shapes, may be greatly reduced by the proper use of the tubes, and by critical adjustments of the circuits into which they function. Unfortunately, however, the fulfillment of these conditions does not prevent the radiation of harmonics due to the antenna or improper coupling systems.

Since a transmission line or an antenna system has a distribution of inductance and capacity, some of the harmonic frequencies generated in the tube-output circuit may correspond with some of the harmonic frequencies of the transmission line or the radiating system and produce excessive harmonic radiation.

It is possible to determine the percentage of the harmonic-frequency content to that of the fundamental frequency by taking the ratio between the harmonic and fundamental fields created at a given distance from the antenna. That is, if the ratio of the two currents generated in the measuring equipment is taken and the radiation resistance of the fundamental and harmonic frequencies carefully measured, a definite relationship of the energy content of the harmonic frequency and the fundamental may be determined by the equation¹

$$\frac{\epsilon_{(\text{harmonic})}}{\epsilon_{(\text{fundamental})}} = \frac{I_{N(\text{harmonic current})}}{I_{a(\text{fundamental current})}} \times \sqrt{\frac{R_H(\text{harmonic radiation resistance})}{R_a(\text{antenna radiation resistance})}} \quad (7)$$

If the harmonic contents are excessive, suitable means must be made to reduce them to negligible values.

4.29. The suppression of harmonics in transmitters is of the utmost importance to reduce the unnecessary interferences which result from this radiation in other frequency channels.

Harmonic radiation, particularly that due to the second harmonic of the fundamental frequency, is the most objectionable. Although

¹ LABUS, J. W., and HANS RODER, The Suppression of Radio Frequency Harmonics in Transmitters, *Proc. I.R.E.*, Vol. 19, p. 949, June, 1931.

this frequency cannot be entirely eliminated, several methods can be arranged for reducing its field intensity to a negligible degree. If the second-harmonic content at a distance of approximately 1 mile from the transmitter does not exceed 0.02 per cent¹ of the energy in the fundamental frequency, the carrier frequency may be considered practically free of harmonic interference. In high-power transmitters the second-harmonic limit has been extended to 0.05 per cent of the fundamental.¹

Several methods may be used to reduce the second-harmonic content of a wave by introducing low-impedance paths to ground at the harmonic frequency or by inserting a high-impedance series-resonant circuit in series with the radiating circuit to block out from the radiating system the undesirable harmonic frequencies.

Figure 4-37(a) illustrates the first method in which the LC circuits are tuned to the second-harmonic frequency and thereby offer to the undesirable harmonics a low-reactance path to ground. The fundamental, or carrier, frequency, on the other hand, is unaffected, since the series-tuned circuits will offer a high reactance to it.

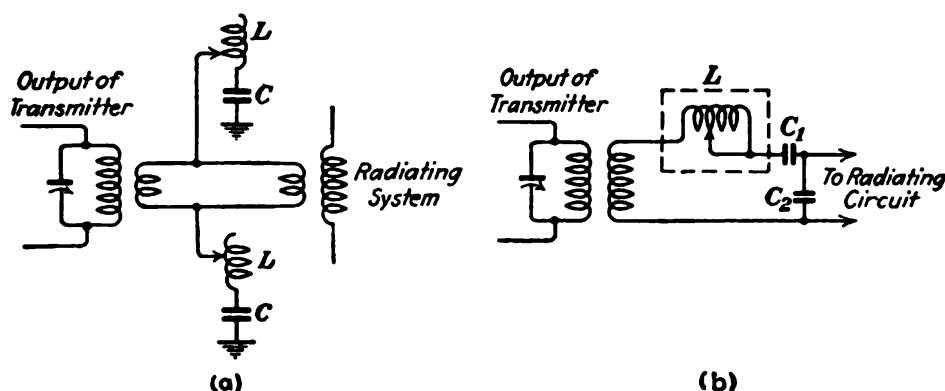


FIG. 4-37.—Harmonic reducing circuits.

Figure 4-37(b) shows the second method in which the series-resonant circuit, LC_1 , is tuned to the fundamental frequency. When the inductance L of the resonant circuit LC_1 is adjusted so that the reactances X_L and X_{C_1} are of equal value, the total effective reactance will be zero. Thus, if this resonant system is placed between the power-amplifier output stage and the antenna radiating system, no reactance will be introduced to block the fundamental frequency, and the energy will be delivered practically unattenuated to the antenna system. The second-harmonic frequency, on the other hand, will not readily pass through the series-resonant circuit since the reactance of the circuit to this frequency is very high. The antenna coupling condenser C_2 is an important part of the harmonic suppression circuit since it acts as a reaction load across this circuit. The voltage developed across it, therefore, equals IX_C .

It has previously been shown that harmonics generated in the plate circuit of a class B or class C amplifier may be reduced by the proper adjustment of the tube voltages and load circuit. However, since the tank circuit may itself generate harmonics when set into oscillation, other preventive means must be used to overcome these harmonics. One of these, and perhaps one of the most extensively used, is the balanced, or push-pull, amplifier as illustrated in Fig. 12-24.

¹ This limit is subject to change as it is set by a rule of the FCC.

With this arrangement it is not only possible to obtain more than double the power output but also to eliminate all of the even harmonics to the transmission-line circuit through T_1 and across C_3 . This is due to the fact that the fundamental-frequency current flowing in each plate circuit is out of phase by 180 degrees. Hence, the even harmonic-frequency currents will flow through C_1 and C_2 in a direction so that the harmonics in the C_3 load circuit cancel.

This condition, however, is only true provided that the circuits are properly balanced; that is, the tubes should be well matched for plate-current flow for a given value of plate voltage and grid bias. The condensers C_1 and C_2 must be of the exact capacity to ensure an equal value of reactance. All leads should be of the same length from the respective condenser and plate connections. If these conditions are not fulfilled, additional even harmonics may also be contributed to the transmission-line load circuit.

Accurate measurements of harmonic radiation can be made only with specially designed supersensitive equipment at some distance from the transmitter, but several simple methods may be used to enable the operator to determine approximately the ratio of the harmonic content to the fundamental frequency radiated.

One of these simple methods uses a precision-type wavemeter which may be placed near the output of the tube circuit to determine the presence of the second harmonic by tuning the wavemeter very accurately to the calibrated setting of the second-harmonic frequency of the carrier wave. If a radio-frequency ammeter is used to indicate this quantity, and a comparison made with the indication when the wavemeter is tuned to the fundamental frequency, an approximate percentage of the harmonic content may be obtained. The coupling between the wavemeter coil and the tank circuit, however, must not be altered, since this will affect the accuracy of the measurements. The current-indicating device must, therefore, have a sufficient range to cover the current readings for both the harmonic and the fundamental values to obtain a direct ratio. Circuit losses in the wavemeter at the higher frequency measurements will affect the accuracy to a slight degree but not sufficiently to prevent a fair comparison.

This same method may be more effectively used by placing the wavemeter at a fair distance from the antenna radiating system, as far removed from metallic structures as possible, and in this way determining if the harmonic content of the actual radiated wave is within the required percentage of the fundamental.

4.30. Parasitic Oscillations.—The oscillation of radio-frequency circuits at frequencies other than that to which they are normally adjusted is generally referred to as *spurious* or *parasitic* oscillation. These oscillations may take place in neutralized radio-frequency amplifiers at

extremely high frequencies owing to stray inductance and capacities in the connecting leads to the plate and grid circuits. This is particularly true in circuits where tubes are connected in parallel because of the paralleling grid and plate leads introducing small oscillatory circuits.

The presence of parasitic oscillations may be readily detected by a large increase in the plate-current readings and an excessive overloading of the tube plates. If the plate circuits are not suitably protected by overload circuit breakers or fuses, the plates may become white-hot and ruin the tube. Choke coils and condensers may also be subjected to severe strain and damage, due to the high oscillating voltages built up across them.

Parasitic oscillations may be prevented by inserting very small radio-frequency choke coils or resistances in series at each one of the grid and plate connections. The chokes must have a very small inductance and should be capable of carrying the normal tube plate-current flow. A non-inductive resistance of approximately 50 ohms may be connected in each grid lead to suppress the radio-frequency grid-current flow generated by the parasitics. A non-inductive resistance may also be connected in each plate lead, but, since this circuit will carry the normal plate-current flow, the resistance would have to be of the heavy-duty variety to withstand the load. Choke coils are preferable, but they must be efficiently designed on Isolantite forms and possess negligible distributed capacity.

II. ULTRA-HIGH-FREQUENCY CIRCUITS¹

4.31. Ultra-high-frequency Systems. General Considerations.—Wave lengths below 10 meters (over 30,000 kilocycles) are generally termed *ultra-short-wave*, *ultra-high*, or *very high frequency emissions*. It is convenient when dealing with these frequencies to specify them in megacycles (mc. or mc./s.), the prefix *mega* meaning one million. As electric waves have been generated as short as 82 millionths of a meter and the gap between the radio and infra-red spectrums bridged, it is possible that practical apparatus utilizing these extremely high oscillations may ultimately come into use. Table A-1, entitled Wave Length—Frequency Conversion Table, which appears in the Appendix, will aid the student of ultra-high-frequency literature in understanding the relationship between frequencies expressed in megacycles (or even centimeters) and wave length in meters. Most practical apparatus for communication purposes operates in the spectrum between 5 and 10 meters, although shorter wave lengths may be used.

There are certain fundamental features of ultra-high-frequency circuits which make them different from circuits operating on the conventional lower frequencies. Distributed capacity and inductance take on

¹ See note on p. 202.

an importance not so noticeable with lower frequencies. Component parts of the circuit must be built with low-loss parts, and mechanical rigidity of the circuit becomes of great importance as any change in relative physical position of circuit parts causes a frequency change with consequent variation in output.

Owing to the very high frequencies involved, skin effect and other circuit losses require the use of conductors offering large surface paths for the currents. Careful consideration must, therefore, be given to apparatus arrangement, and leads must be kept very short or eliminated wherever possible.

When the very high frequencies are to be used, the inter-element travel time of the electrons in the tube becomes important. It has been found that tubes especially designed for ultra-high-frequency generation must have electrodes of comparatively small area and a structure short in the axial direction.

4.32. Ultra-high-frequency Oscillators. *a. Regenerative Oscillators.* These oscillators, as used for practical radio purposes, are divided into two groups: (a) regenerative oscillators, (b) electron oscillators. Among the first of the practical ultra-high-frequency vacuum-tube oscillators was the arrangement developed by Gutton and Touly about 1919. This oscillator employed a very simple circuit which consisted of a single turn of inductance between the plate and the grid of the tube, with a grid condenser and grid leak, arranged as shown in Fig. 4-38(a). This circuit

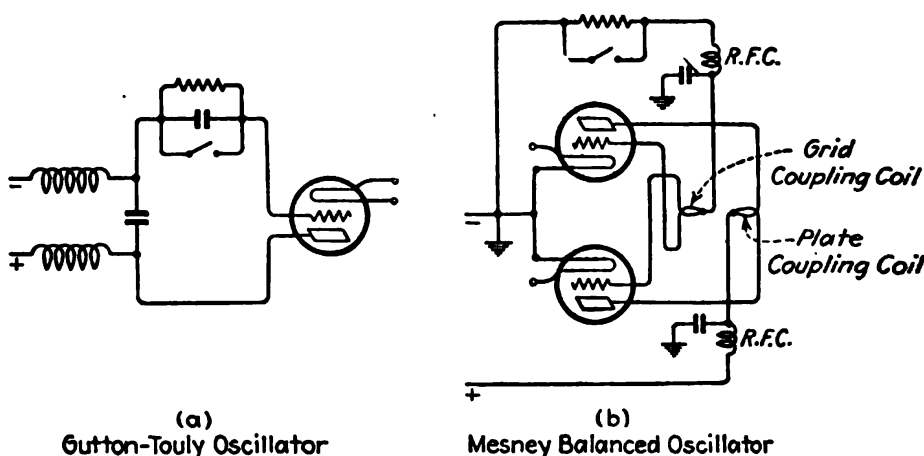


FIG. 4-38.—Ultra-high frequency oscillators, regenerative types.

tuned down to 2 meters and is the fundamental-circuit basis for most of the single-tube regenerative ultra-high-frequency oscillators used at the present time.

Another widely used fundamental circuit is that developed by Mesney in 1924 and which is shown in Fig. 4-38(b). This is a two-tube balanced circuit and gives stable oscillations down to 1.5 meters.

For wave lengths between 5 and 10 meters the conventional tuned-plate tuned-grid oscillator is commonly used. This oscillator when used

with a radio-frequency power amplifier is usually capacity coupled to the amplifier.

The principal difficulties with ultra-high-frequency oscillators are caused by the inter-electrode capacity of the tube or tubes being too high and because it is impossible to get proper impedance values with the low L and C used in the tuned circuits. It must also be remembered that when a tube oscillates, electrons pass to and fro within the tube. As the frequencies become higher, the length of time it takes for the electrons to complete their inter-electrode journeys becomes a limiting factor on the oscillating frequency.

Lieutenant Wenstrom, U.S.A., reports¹ the following practical results with ultra-short-wave oscillators of the regenerative type:

1. Carefully used, the Lecher system is a precise method of wave-length measurement (± 0.01 per cent).
2. Relative power output and efficiency of ultra-short-wave oscillators under various electrical conditions can be determined with about ± 3 per cent precision by means of a closely coupled high-resistance loop in series with a thermoammeter.
3. Absolute efficiency can be determined by the heat-radiation method with better than ± 2 per cent accuracy.
4. The absolute efficiency of ultra-short-wave oscillators operating under average optimum conditions is about 30 to 40 per cent.
5. Operating with grid resistance, the single-tube oscillator is more efficient than the balanced oscillator at low or high plate voltage, while at moderate plate voltage the two circuits are about equal in efficiency.
6. Operating with grid battery, the balanced oscillator is more efficient than the single-tube oscillator at high negative grid bias, while with moderate grid bias the two circuits are about equal in efficiency.
7. In the optimum grid-resistance region (5,000 to 10,000 ohms per tube), a 2-to-1 variation of grid resistance has little effect on output or efficiency.
8. With zero grid resistance the efficiency of both types of oscillators is low.
9. Considerable changes in filament voltage (± 20 per cent) have little effect on output and efficiency of oscillators employing thoriated-filament tubes.
10. In properly designed circuits the filament-emission demands are not far from normal.
11. The variations of oscillating current, plate current, and grid current in ultra-short-wave oscillators are less than 5 per cent during an hour of continuous operation.
12. The wave length of an ultra-short-wave oscillator varies with time after plate voltage is applied due to the plate-grid-capacity change caused by heating.
13. The wave length of a balanced oscillator in general increases with time at a decreasing rate. The change is about 0.01 per cent per minute after 8 min. operation.
14. The wave length of a single-tube oscillator at first decreases with time owing to the rapid capacity change in the external circuit condenser, then increases with time owing to the predominant plate-grid-capacity effect.
15. The wave length of either type of oscillator varies only slightly with changes in filament voltage. It varies markedly, however, in response to plate- or grid-voltage changes.

¹ This list of conclusions is taken from the paper, An Experimental Study of Regenerative Ultra-short-wave Oscillators, by William H. Wenstrom, *Proc. I.R.E.*, Vol. 20, No. 1, January, 1932.

An entirely different method of producing ultra-high-frequency oscillations was discovered by Barkhausen and Kurz and reported by them in 1920. They called this circuit an *electron oscillator* and its principal difference, in so far as circuit is concerned, is that the grid is maintained at a high positive potential while the plate is at a zero or slightly negative potential. The theoretical operation is as follows.

b. Electron Oscillators.—In the Barkhausen-Kurz oscillator system, shown in Fig. 4-39, the oscillations are due entirely to the to-and-fro movement of electrons between the grid and filament of the vacuum tube. This is to say, the oscillating condition of the electrons takes place solely within the tube and is not determined by the circuit constants as in the conventional regenerative oscillator.

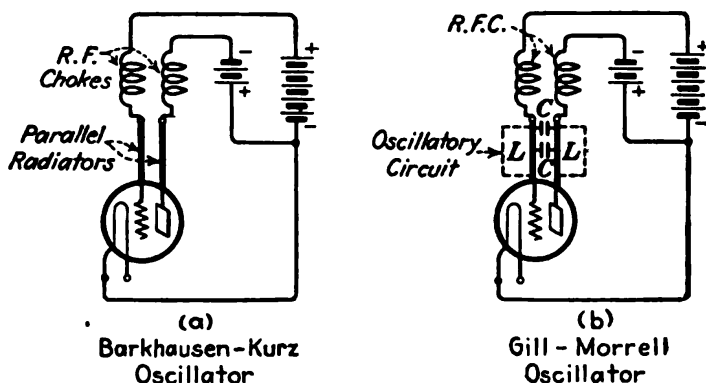


FIG. 4-39.—Ultra-high-frequency electron oscillators.

The oscillating electrons are a result of a high positive potential being applied to the grid and a small negative potential to the plate. As the electrons are accelerated toward the grid at high speeds, they pass beyond the grid lateral structure toward the plate but are immediately pushed and pulled back to the grid. This movement of electrons back and forth through the grid structure apparently causes a displacement of the free electrons in the grid wires, first in one direction and then in the other, resulting in an oscillating potential change between the grid and the plate of the tube. Hence, if these oscillations are of an amplitude great enough to develop sufficient power to overcome the circuit losses, the oscillations will be sustained.

The oscillations produced by the oscillations of electrons within the tube are called *Barkhausen-Kurz* (or B-K for short) *oscillations* and the inventors of the circuit claimed that the frequency of oscillation within the tube was not affected by adjustment of any external circuit connected to the tube. Later discoveries by Gill and Morrell showed that, if an external circuit was connected to a B-K oscillator, it would under certain conditions oscillate too, and that the frequency of these oscillations which then took control of the circuit was the frequency of the tuning system and they were affected by the adjustment of the external connections. These new oscillations are known as *Gill-Morrell* (G-M) *oscillations* and it has been shown that whether the B-K circuit produces B-K or G-M oscillations depends upon the circuit adjustments. The Gill-Morrell oscillator is in fact a Barkhausen-Kurz circuit in which the

external circuit connected to the grid and plate is a certain critical value which produces G-M oscillations. A slight readjustment of this circuit may throw the oscillator back to B-K characteristics. In other words, whether an electron oscillator is B-K or G-M is only a matter of circuit adjustment which is very critical in nature.

The formula for wave length for the B-K oscillator as given by F. B. Llewellyn of the Bell Laboratories is

$$\text{Wave length in centimeters} = \frac{670d}{\sqrt{E_g}} \quad (8)$$

for tubes with cylindrical electrodes and equal grid-cathode and grid-plate spacings, where d is the diameter of the plate in centimeters and E_g is the grid voltage.

Both of these oscillators are capable of producing extremely high frequencies, in the order of 300,000 kilocycles (1 meter) and up, but are limited to very small powers.

Specially designed tubes are required for these oscillators to keep the efficiency extremely high during the period of oscillation, otherwise the oscillations are of slight duration.

4.33. Modulation of Ultra-high Frequencies.—For the regenerative type of oscillator the Heising constant-current system is very satisfactory and can be applied to high-level modulation on M.O.P.A. circuits.

A considerable study of modulation of B-K oscillators was made by Hollmann who reported, in 1928, several schemes for accomplishing such modulation as follows:

a. In one, the secondary of the microphone transformer was connected in the anode (negatively biased) lead. In another, the anode of the modulator tube was connected to the grid (high +) of the oscillator.

b. With a receiver similar to the oscillator but having headphones connected in series with the anode (negative bias), circuit telephone transmission was accomplished up to a distance of 500 wave lengths.

Owing to the relatively greater permissible width of the operating spectrum employed with ultra-high-frequency emissions, high modulation frequencies are also permissible which is of advantage under certain conditions of service.¹

4.34. Ultra-high-frequency Transmitters. *a. General Considerations.* The last portion of the radio-frequency spectrum to be developed for communication purposes is that containing the ultra-short or ultra-high-frequency waves below 10 meters, that is, above 30,000 kilocycles.

One of the first of these systems put into practical commercial use was installed by The Mutual Telephone Company for the Interisland

¹ Ultra-high-frequency wave propagation is covered in Chap. 7 on Antennas and Wave Propagation.

Telephone System in Hawaii in 1931. Since then similar systems have been installed for general communication purposes by the United States Army and Navy, the state forestry services, the broadcasting companies for remote pickup purposes, and a constantly increasing number of police departments. The possibilities for further adoptions seem limitless owing to the restricted nature of the radiations employed.

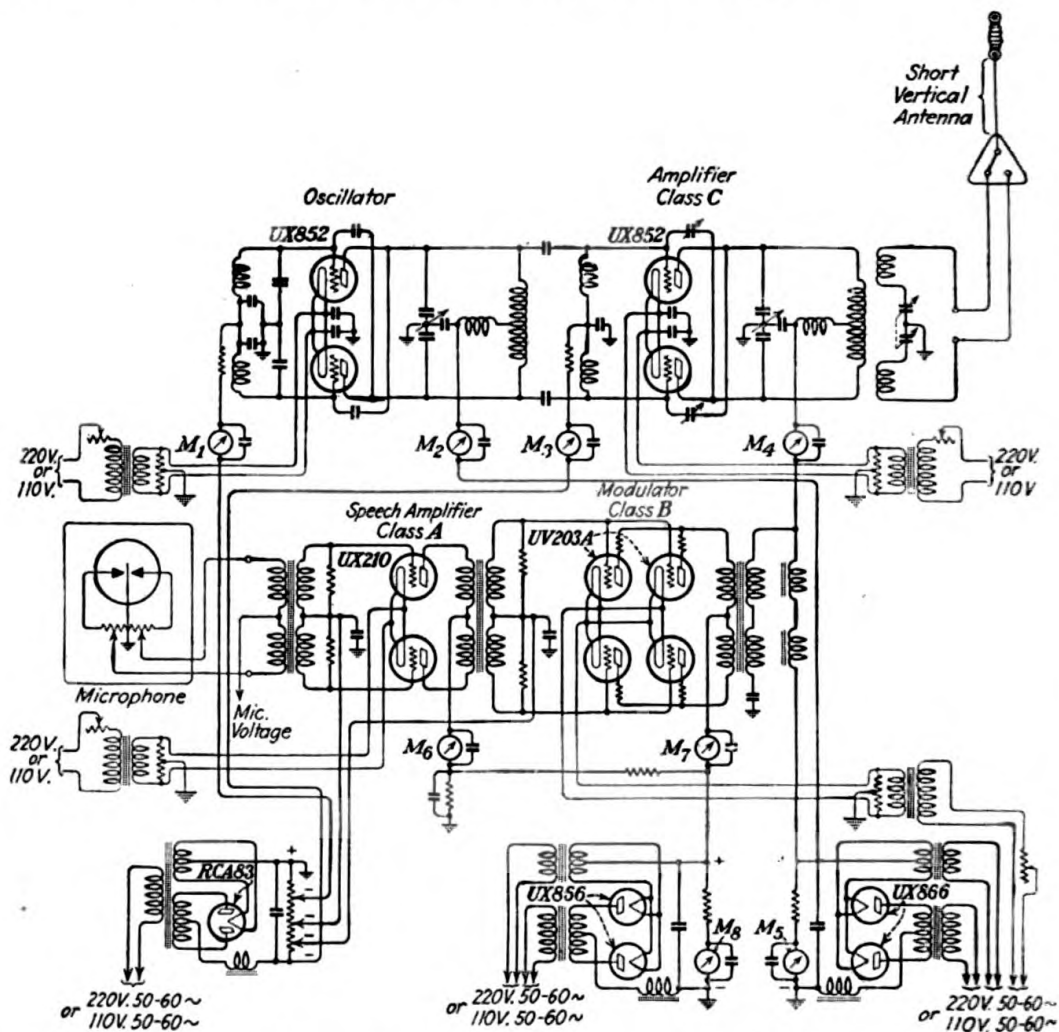


FIG. 4-40.—Ultra-high-frequency radio-telephone transmitter. (Courtesy of RCA Manufacturing Company, Inc.)

b. A 100-watt Radio-telephone Transmitter: RCA Victor Type ET-5012.—This transmitter is designed to cover the frequency band of approximately 30 to 36 megacycles, but it is possible to operate the transmitter in either a lower or higher frequency band than that for which it was primarily designed by changing various inductance coils and the antenna tuning to be in accordance with the desired frequency. A simplified schematic diagram of this transmitter is shown in Fig. 4-40; the control circuits have been omitted for simplification. A close study of this diagram will make clear the significant features of the circuit.

The power amplifier is operated as class C giving a high plate efficiency. Both the oscillator and the amplifier are self-biased, thus reducing the number of necessary adjustments. Neutralization is accomplished by means of an adjustment within the protective screening. Once this adjustment has been made, the neutralizing capacitor may be locked in place.

Three vernier dials are provided on the front panel which provide for all tuning necessary. These dials tune the oscillator, amplifier, and antenna circuits as shown in the diagram and are fitted with a locking device to insure that the transmitter will not be accidentally thrown out of adjustment.

Due to the use of the push-pull master oscillator, the frequency stability is well within the limits required for reliable communication in the ultra-short-wave spectrum.

Provision is made for 100 per cent modulation in this transmitter, thereby increasing effectively the range and the signal-to-noise ratio of the equipment. Accordingly the final power stage is specifically designed to handle 400 watts peak power without introducing distortion.

The audio equipment is designed to give faithful reproduction of all speech frequencies; that is, the frequency response is flat to within 2 db from 100 to 5,000 cycles. The audio-input circuit is designed to operate from a 500-ohm line at a level of +6 db (0 db = 12.5 mw. in 500 ohms) in order to obtain proper 100 per cent modulation. This transmitter operates with either the carbon-, condenser-, or velocity (ribbon)-type microphone.

All component parts of the radio-frequency circuit are insulated from their base by low-loss Isolantite supports. Isolantite antenna posts project through the top cover of the housing. All items, including the separate power-supply systems, are completely enclosed in shields to prevent pick-up.

The transmitter requires approximately 1.6 kw. from the line. During periods of stand-by between dispatches, the power consumption is reduced to approximately 400 watts.

The following meters indicated on the diagram are provided:

M_1 Grid current of master oscillator.	amplifier.
M_2 Plate current of master oscillator.	M_6 Plate current on speech amplifier.
M_3 Grid current of power amplifier.	M_7 Plate current of modulators.
M_4 Plate current of power amplifier.	M_8 Plate voltage on speech amplifier and
M_5 Plate voltage on oscillator and	modulator.

The transmitter is usually placed in a room as near the antenna as possible, with access through a window for a pair of wires running to the antenna. The antenna is a single vertical wire, approximately 10 to 14 ft. long, drawn alongside a 25- to 40-ft. pole placed on the roof, or as high as possible.

c. Radio-telegraph Transmitter. Either the Gutton-Touly oscillator or the Mesney balanced oscillator, shown in Fig. 4-38, could be used for radio-telegraphic communication by coupling them to an antenna system. Keying may be accomplished by inserting a key in the grid return or by placing a radio-frequency choke in the grid circuit, shunting the key around the choke and thus accomplishing keying.

Because of the difficulty of frequency stabilization on the ultra-short waves, ICW emission is permitted. This is accomplished by using an alternating-current plate potential or by modulating the oscillator

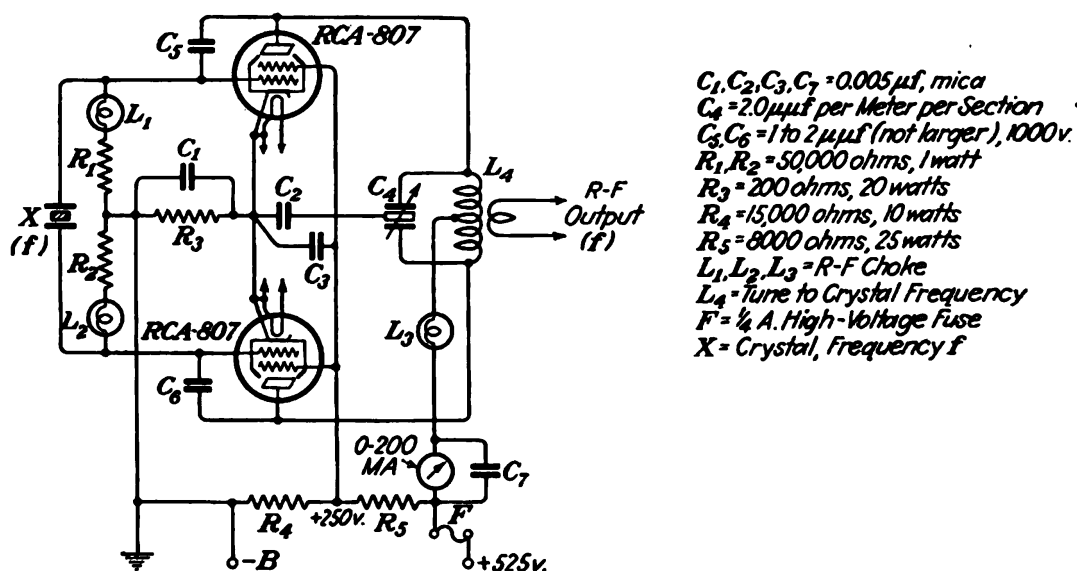


FIG. 4-41.—Five-meter push-pull oscillator circuit. (Courtesy of RCA Manufacturing Company, Inc.)

plate current by means of an audio oscillator as was described earlier in this chapter in connection with the intermediate-frequency marine transmitter.

Radio-telegraph transmitters are infrequently used on the ultra-high-frequency bands as the advantages of radio-telephony in the absence of static and over limited ranges more than outweigh the expense and difficulty of employing speech-modulated signals.

A very satisfactory 5-meter push-pull oscillator circuit, designed by the RCA Radiotron Division of the RCA Manufacturing Company Inc., and reproduced from their *Technical Manual TT3* by permission, is shown in Fig. 4-41.

NOTE.—The terminology defining the bands in the useful radio spectrum as given in the table on page 148 was announced by the FCC too late to be used throughout this text. Hence, due allowance should be made for this in reading text matter covering frequencies above 30 megacycles.

CHAPTER 5

RECEIVING-CIRCUIT PRINCIPLES

The radio-frequency amplifier and the vacuum-tube oscillator described in the preceding chapter are used in both transmitting and receiving circuits. Regardless of the circuit in which they are used their theory of operation is the same. Therefore, these applications of the vacuum tube in receivers will not be further explained. The remaining features of the receiving circuit may now be logically studied.

5.1. General Receiving Considerations.—The radio receiver is a very important part of any radio system, and when it is designed it must be considered as part of a definite system.

All radio receivers have certain features in common, such as sensitivity and selectivity. On the other hand, certain classes of receivers have characteristics not required in other types. For example, a broadcast receiver must have fidelity (quality) in addition to sensitivity and selectivity. The fidelity factor is not required of receivers such as are commonly used in aeronautical and police work. Also it is undesirable that receivers radiate radio-frequency energy. These and other problems will be treated in this chapter.

MULTIGRID TUBES, DETECTOR, AND AUDIO AMPLIFIER

5.2. The Screen-grid Tube.—Figure 5-1 shows the electrode arrangements (a) of screen-grid tubes and the inter-electrode capacity (b) between its various elements.

In the ordinary three-element vacuum tube there is existent a considerable amount of inter-electrode capacity between the grid and the plate which stores up a heavy electrostatic field between these elements.

The presence of this capacity between the grid and the plate not only decreases the amplifying efficiency of the tube, owing to the increase in space charge, but also introduces circuit reactions between the plate and grid circuits. This is particularly objectionable in radio-frequency amplifying circuits because of the possibility that feedback through the inter-electrode capacity may set the tube into regeneration or oscillation. Radio-frequency amplifiers must not go into self-oscillation if circuit stability and minimum distortion are to be maintained. Self-oscillation may be prevented by a neutralization system in which the internal capacity effect of the tube is balanced out (see Balance Circuits, Sec. 3.14, and Neutralization of a Transmitting Circuit, Sec. 3.15).

In radio-frequency amplifiers where the screen-grid tube is used, this feed-back possibility is, however, greatly reduced because of the reduction

in the inter-electrode grid-to-plate capacity caused by the interpolation of the screen grid between these two elements. The result of inserting the screen grid is effectively to screen the control grid from the plate so that changes in plate potential have practically no effect on the electrostatic field around the control grid. Thus there can be no internal feedback in the tube.

In view of the greatly reduced electrostatic field within the tube, the amplification factor, or μ , of the tube will be greatly increased, thereby increasing the efficiency of the tube as a voltage amplifier in radio-frequency and audio-frequency circuits. Incidentally, the alternating-current plate resistance R_p of the screen-grid tube will also be greatly increased, as the plate current is determined almost entirely by the screen voltages.

It is of course very important that the load impedance of a screen-grid tube must be at least equal to the tube impedance if a proper transfer of energy is to be expected. For example, if an ordinary triode, having a plate resistance R_p of, say, 10,000 ohms, functioning efficiently into its matched load of an approximately equivalent resistance, is replaced by a tube of the screen-grid variety, having a plate resistance of approximately 500,000 ohms, no appreciable increase in amplification can be expected unless the load impedance is increased to effect an approximately matched condition. This condition may be easily arranged for in radio-frequency amplifiers by simply adding more turns to the load inductance to bring up the inductive reactance. In low-frequency or audio amplifiers, however, this would be considerably more difficult because the low frequencies between 30 and 200 cycles would not produce as much reactance across the load impedance as the higher audio frequencies, unless the units

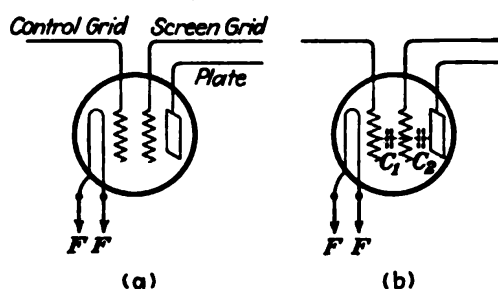


FIG. 5-1.—(a) Screen-grid tube; (b) C_1 and C_2 represent interelectrode capacities.

were designed to have a very large inductance so that when the lowest audio frequency is applied it will effect a reactance which will be an approximate match to the tube-plate resistance. This would require a specially designed transformer of large physical dimensions. In general practice where screen-grid tubes are used as detectors, they are usually coupled

into a resistance-coupled audio-frequency amplifier where it is a relatively simple matter to match the load to the tube impedance by using a plate-coupling resistance of a value somewhere between 250,000 and 500,000 ohms (see Sec. 5.8).

Variable- μ Tube.—This type of tube is of the typical screen-grid variety as illustrated in (a), Fig. 5-1 or a pentode as shown in Fig. 5-2(b). The name *variable- μ* has been applied to this tube owing to its ability to control amplification by varying the

voltage upon its control grid. That is to say, the structure has been so designed that the cutoff point of the I_p - E_c characteristic curve is such that a considerably higher grid-bias voltage is required to produce cutoff, relative to that in the ordinary screen-grid tube.

This may be more clearly seen if the relative I_p - E_c characteristic curves of both tubes are examined in Fig. 5-2(a). It will be noted that the I_p - E_c curvature of the ordinary screen-grid tube in curve (a) is more pronounced than that in curve (b) of the variable- μ tube. This indicates that, if an excessive grid swing is applied to the ordinary screen-grid tube, the asymmetry due to the lower curved area will produce radio-frequency distortion. In the variable- μ tube the approach to the cutoff point is more gradual, and consequently much more signal can be applied before distortion results.

Furthermore, the minimizing of the steepness at the lower portion of the characteristic curve decreases the possibility of distortion due to the intermodulation of the desired signal with that of an interfering signal. This is commonly known as *cross-talking* or *cross-modulation interference*.

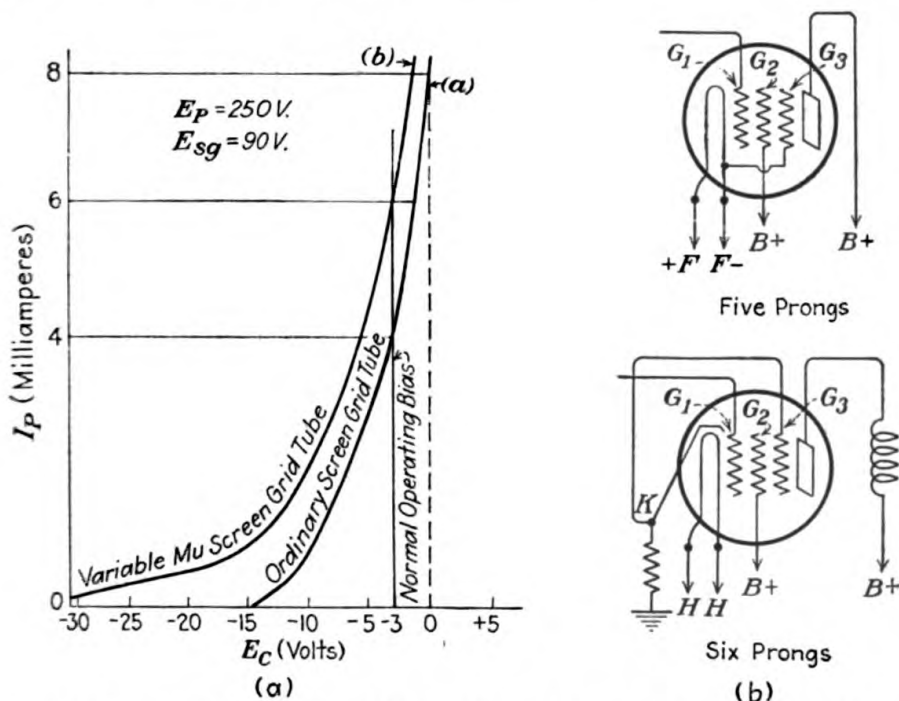


FIG. 5-2.—(a) Characteristics of variable-mu tube; (b) pentode connections (G_1 = control grid, G_2 = screen grid, G_3 = suppressor grid).

5.3. The Pentode Tube.—Figure 5-2(b) illustrates two arrangements of the pentode variety of screen-grid tubes. In addition to the screen grid previously explained, another grid called a *suppressor* is placed close to the plate element in the tube. This grid may be connected directly to the filament or the cathode of the tube as illustrated in the figure, thereby placing it at ground or zero potential. In some types of tube this connection is made internally, to either the filament or the cathode, depending upon the type used. Hence no difference of potential exists between this grid and the filament, since both are at the same electrical level or potential. Its function, however, is extremely important owing

to its effect upon the negative field produced in the immediate vicinity of the plate.

When electrons are bombarding the plate in tremendous numbers, in tetrode and pentode tubes, the impact of the electrons against the plate causes the plate to emit electrons. This effect is called *secondary emission*. These electrons produced at the plate may be collected by the screen grid, causing an increased flow of screen-grid current and a consequent reduction or dip in the plate characteristic. This dip will produce serious plate distortion and resultant harmonic generation. If, however, a grid is located very near to the plate and at ground potential, the emission of secondary electrons from the plate will be repelled. This prevents the secondary electrons from reaching the screen grid and reduces the possibility of plate distortion. In addition the repelling action of the suppressor grid permits a relatively larger development of power in the plate circuit without distortion.

Owing to the desirability of the suppressor action, the pentode has almost entirely replaced the ordinary screen-grid tube in receiving circuits. This change gives a tube in which, over the operating range, the plate current is essentially independent of plate voltage, and the tube acts like a constant-current generator. The plate resistance is extremely high, and therefore the usual method of computing stage gain becomes useless. If, instead of considering the tube as a voltage generator, we consider it as generating a plate current $I_p = E_g G_m$, then the voltage across the load equals $I_p R_L = E_g G_m R_L$, where G_m is the mutual conductance of the tube. The gain of the stage is then

$$G = \frac{I_p R_L}{E_g} = G_m R_L \quad (1)$$

This equation is not accurate for the triode amplifier, as it assumes that the plate current does not vary with the plate voltage.

The pentode tube as a power amplifier in receiving circuits, therefore, has some advantages over the triode type of amplifier, particularly in that the pentode has the ability to develop considerably more power and requires only about one-third of the signal voltage for a given amount of power.

Hence, since the amplifying ability of the tube is relatively greater for a given impressed signal voltage, it is possible to eliminate one of the preceding voltage-amplifier stages and thereby reduce the number of tubes.

The Power Pentode Load.—It has been previously explained that the output load of the vacuum tube should at least be equal to the plate impedance (R_p) of the tube, if a maximum power is to be developed in the load circuit. It was also shown that the output load of an audio-frequency power-amplifier triode should be twice the plate resistance of the tube, if fidelity is to be obtained at the low audio-frequency spectrum.

This is mainly due to the low plate resistance of the power triodes, between 1,500 and 3,000 ohms.

The power pentodes, on the other hand, have a considerably higher plate resistance, approximately between 10,000 to 60,000 ohms. If, therefore, the load-impedance values were based upon triode conditions, considerable distortion would result owing to the increased curvature of the tube's dynamic characteristic, which is inherently more curved than that of the triode. This curvature causes greater harmonic distortion in the pentode. Hence, in order to reduce the power developed by the harmonics in the output-load circuit, a much lower value of load resistance relative to the plate resistance is used. The optimum value of the load resistance in power pentodes is generally between 5,000 and 15,000 ohms.

The maximum undistorted power output of a pentode may be calculated from the formula

$$P_{\text{undistorted}} = 0.33 \times E_p \times I_p \text{ watts (approx.)}$$

The constant 0.33, or one-third, is derived from the plate efficiency of a pentode when operating into a low load impedance. Under these conditions the plate efficiency is approximately $33\frac{1}{3}$ per cent.

For example, where the output-load resistance for a triode power amplifier having an R_p of 2,000 ohms must be at least 4,000 ohms, the output-load resistance of a power pentode with a plate resistance of 60,000 ohms would be approximately 7,000 ohms. These conditions must be thoroughly fulfilled if good quality and power are to be obtained. The value of the output-load resistance of a pentode tube may be calculated approximately from the formula

$$R_o = \frac{E_p}{I_p}$$

where E_p = the operating voltage and I_p = the operating plate current; it being assumed that the bias is correctly adjusted for these conditions.

For example, the 47 pentode tube requires a plate voltage E_p of 250 volts, a bias voltage E_c of -16 volts, and a screen voltage E_{sc} of 250 volts. Under these conditions a plate current of 30 ma. (0.030 amp.) will flow. Hence the approximate value of the load resistance for this tube will be

$$R_o = \frac{E_p}{I_p} = 8,000 \text{ ohms (approx.)}$$

5.4. Beam Power Tubes.—For high audio outputs the class A operated triode in a push-pull circuit is ideal in that there is no distortion so long as no grid current flows. Under these conditions, however, a large signal input is required, and the efficiency is low. This poor efficiency is due to a maximum flow of plate current occurring at low plate voltages where the conductance of the tube is low.

The conventional power pentode was provided as a partial solution in that it operates with a higher efficiency. This higher efficiency is due to the higher amplification factor of this tube and its ability to permit the plate voltage to swing with the audio signal well toward the zero voltage value. This tube would be ideal for high-power audio outputs when operated as a class A push-pull amplifier except that a rather large third-harmonic distortion content is present in the output.

The high third-harmonic component in the output of the conventional pentode is caused by a non-uniformity in the electron density between the screen and the plate. This condition is in turn caused by an insufficient density of electrons in the stream to the plate. To remedy these conditions, the so-called *beam power tube* was designed.

In the beam power tube, a cross section of which is shown in Fig. 5-3,

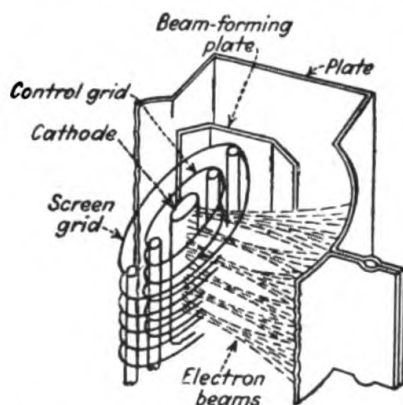


FIG. 5-3.—Internal structure of type 6L6 beam power tube.

non-uniform density of electron stream and insufficiency of electrons are corrected by beam-forming plates, which concentrate the electron stream into a well-defined beam as shown in the illustration.

In the tetrode type of beam power tube, the beam-forming plates function in place of an actual suppressor to repel secondary emission. This they do by virtue of their physical shape, which causes their bent edges to coincide with that portion of the beam wherein it is desired that the space charge shall be intensive enough to prevent

stray secondary electrons from returning to the plate. Hence, a suppressor grid is not needed.

In the pentode type of beam power tube an actual suppressor grid is used to repel secondary emission.

Over-all efficiency of the beam power tube is increased by a careful placement of the electrodes within the tube so that the beam-forming plates and the grids will operate on certain critical portions of the electron stream.

Typical examples of the tetrode-type beam power tube are the 6L6 and the 6L6-G. Beam power tubes using an actual suppressor are the 6V6 and the 6V6-G.

The tetrode type of beam power tube has found some application also as a crystal oscillator in transmitter circuits.

5.5. The Vacuum-tube Detector.—The purpose of a vacuum tube as a detector or demodulator is to rectify the incoming signal of high frequency to one of low or audible frequency. This is accomplished by

¹ Condensed in part from R. S. Burnap, *New Developments in Audio Power Tubes*, R. C. A. Rev., Vol. I, No. 1, July, 1936.

adjusting the vacuum-tube plate voltage and grid bias so that a symmetrical signal of high frequency may be rectified into asymmetrical waves or group pulses. This condition is necessary in order that the signals may pass through a high impedance such as a telephone or primary winding of an audio-frequency transformer. The two methods by which rectification may be obtained are known as *plate* detection and *grid* detection.

5.6. Plate Detection.—When an alternating e.m.f. is applied across the grid and filament as illustrated in Fig. 5-4(a) the normal or steady plate-current flow will be affected in accordance with the character of the

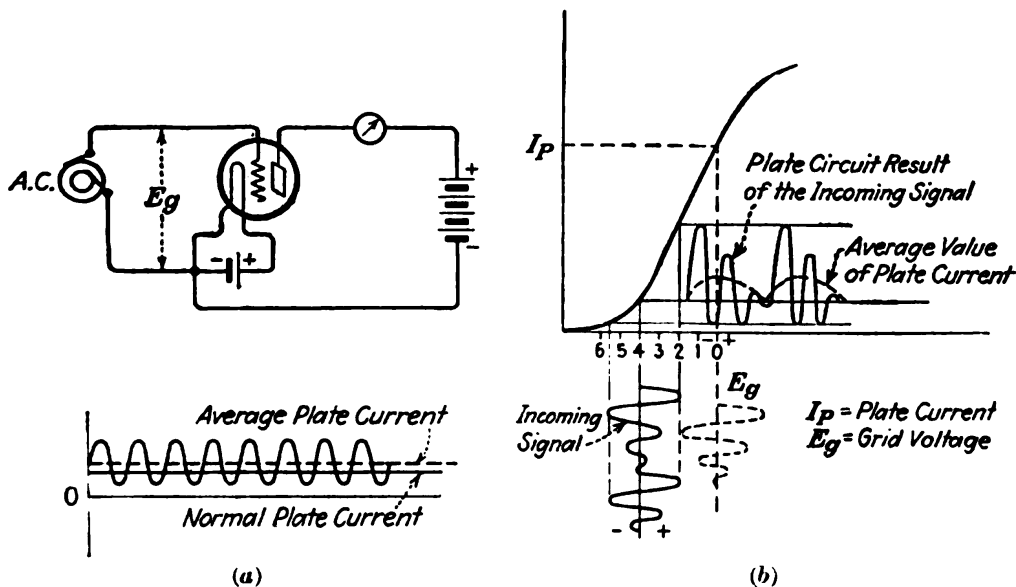


FIG. 5-4.—(a) Triode plate-current variations; (b) graph illustrating rectification.

potential change on the grid. That is to say, when the alternating potential is applied, a plate current *above* normal will flow when the grid is charged positive with respect to the filament, and a plate current *below* normal will flow when the grid is charged negative with respect to the filament. The tube may be so operated that the increases in the plate current over the normal value may be much more than the decrease below the normal value. The average plate current, therefore, under these conditions is much more than the normal value. Consequently, if a signal variation of radio frequency is applied to the grid of the tube, the signal is not only amplified but also rectified. If, therefore, the signal is of a damped or modulated character, the plate current variations will be asymmetrical in shape and thus make it possible for the audible groups or pulses to pass through the telephones or the primary winding of the audio-frequency transformer.

Figure 5-4(b) illustrates the condition in which a modulated signal wave is applied to the grid of a tube operating as a detector. The asymmetry is fulfilled by the adjustment of the negative grid bias E_g , so that the signal is applied below the straight portion or at the knee of the characteristic curve. This produces a rectified com-

ponent in the plate circuit which develops a voltage across the load impedance of the telephone or primary winding. Since the voltage applied to the plate of the tube is maintained constant by the power supply, it can readily be seen that, when an incoming signal develops an IR or voltage drop across the load, the actual voltage on the plate of the tube will be varied accordingly. This variation may then be transferred to a succeeding or amplifying circuit through a coupling transformer or resistance.

In all radio-frequency detecting circuits, it is very important to build up a maximum audio-frequency voltage across the load impedance if the proper efficiency is to be obtained. In view of the fact that there are two components present in the plate circuit of a detector tube, namely, the carrier or radio frequency and the modulation or audible frequency, a small radio-frequency by-pass condenser must be shunted across the load impedance. This condenser must offer a high impedance to the modulated-frequency component in the plate circuit and a low impedance to the radio-frequency or carrier component. If this condenser offers too much reactance to the radio-frequency signal, some of the voltage will be spent in forcing current through the high-impedance primary load and consequently will result in a reduction of the signal voltage acting on the load.

Plate detection is generally used where signal voltages are of large magnitude such as is true when a number of stages of high-gain radio-frequency amplification precede the detector tube. If the signal voltage is small when operating a detector near the cutoff point of the I_p - E_g characteristic curve, the amplification will follow a square law and the result will not be linear. If, on the other hand, the signal voltages are of a large magnitude, and plate detection is used, rectification will be fairly linear and better quality will result.

5.7. Grid Detection.—In the grid-detection method of rectifying or demodulating a radio signal the entire process of detection takes place in the grid circuit, and the plate circuit merely functions as an amplifier. Figure 5-5 illustrates a circuit arrangement employing the grid-rectification principle.

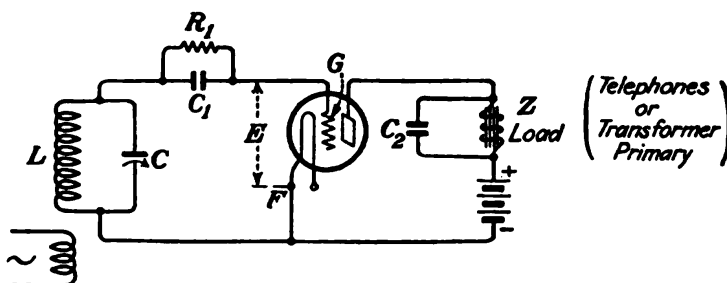


FIG. 5-5.—Grid-leak detector circuit.

When an incoming signal of modulated radio frequency is applied across the oscillatory circuit LC establishing an e.m.f. across the points GF , the plate current will be varied in accordance with the incoming modulated frequency; that is, the audio-frequency component will pass through the load impedance Z and the radio-frequency component through the reactance C_2 . In order that these conditions be fulfilled,

the potential of the grid must be such that it will take current. Since the audio plate-current variations depend almost entirely upon the audio-frequency voltages set up on the grid, it is necessary to build up a maximum voltage on the grid by inserting a small condenser C_1 in series with the grid. This condenser provides the necessary high impedance for the low-frequency modulated groups and a low impedance for the high-frequency signal variations.

A very important feature in connection with the condenser C_1 is that its reactance must be very large in comparison with the grid-circuit resistance. If this is not done, frequency distortion will result owing to the low grid impedance. The condenser, therefore, should have a capacity of between 0.0001 and 0.00025 mf. to offer a maximum IZ drop to the low frequencies and a minimum drop to the radio frequencies.

The purpose of the grid resistance or grid leak R_1 is to allow the accumulated charges of electrons on the grid, which gather during the positive halves of the signal voltage, to become dissipated, otherwise the grid would build up an excessive charge of electrons and become erratic in its behavior. Hence, it may be said that the grid-leak resistance prevents the grid from "floating" by allowing a continuous conduction of direct current during the intervals in which signal voltages are impressed upon the grid. It is apparent that the greater the incoming-signal voltage, the larger will be the value of current flowing through R_1 ; consequently, its resistance value should be kept low in all cases where high-gain radio-frequency amplifiers are used preceding the detector tube. Furthermore, the larger the value of the signal voltage on the grid, the greater will be the negative grid bias due to the electron flow through the resistance from the filament to the grid when the grid is charged positively. Thus, when the grid bias increases, the grid-circuit resistance also increases, thereby raising the possibility of distortion at the higher audio frequencies. It is, therefore, essential that the grid-leak resistance should not exceed the value which will introduce serious audio-frequency distortion. Where higher values of resistances (above 3 megohms) are used, the grid-condenser value should be reduced to the order of 0.0001 mf. This greatly increases the sensitivity of the detector owing to the larger audio-frequency voltages which may be built up across a small capacity in view of its greater IZ drop.

5.8. Power Detection.—A power detector is essentially a plate-detection system in which the plate voltage and grid bias are so adjusted that a relatively larger audio-frequency power output may be obtained. A plate voltage of approximately 200 volts with a grid bias adjusted almost to the point of plate-current cutoff, about -20 volts, will give efficient results.

The important consideration for the proper operation of a plate power detector is that the grid voltage built up by the incoming signal must never be allowed to swing the grid positive. It is, therefore, necessary that the signal voltage at 100 per cent modulation does not at any time exceed one-half the negative grid-bias voltage that is being used. The sensitivity of the detector, therefore, is greatly reduced, but the quality of reproduction with strong signals is evidently much superior to any other method of detection (except diode detection, Sec. 5.15).

The possibility of obtaining a fairly linear output across the external-load impedance with this method of detection is much better than with the grid-rectification system, particularly when receiving signals of 100 per cent modulation.

This condition may be clearly seen if we assume a modulated radio-frequency signal applied to the grid of a detector tube operating near the cutoff point. If this signal has its radio-frequency amplitude varied to 100 per cent modulation, then the resultant audio-frequency output will depend on the I_p - E_g characteristic curve. If the curve should resemble a characteristic (curve) as shown in Fig. 5-6(a), the resultant

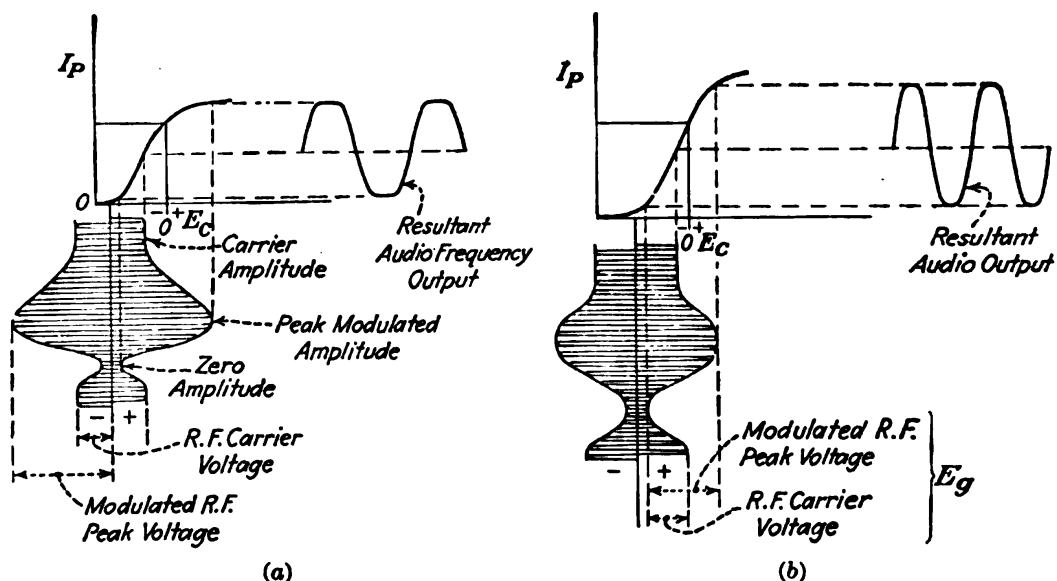


FIG. 5-6.—Wave-shape characteristics: (a) distorted, (b) symmetrical.

audio frequency will not resemble a symmetrical reproduction of the signal envelope, but a box-type wave which will produce serious distortion. It is also evident that, if the C bias is operated slightly beyond cutoff, the lower portion of the audio output wave will also resemble a box-type characteristic. Great care must be taken, therefore, to use a tube which will operate along the linear portion of the characteristic curve so that the audio-frequency output will resemble a symmetrical wave shape of the modulated signal envelope as illustrated in Fig. 5-6(b). This condition may be obtained by preventing the modulated peak voltages from rising too high and extending into the curve portion areas. It is apparent, therefore, that low-percentage modulated radio-frequency waves, and waves having low radio-frequency peak voltages, may be expected to provide the most symmetrical output. However, if the tube is properly designed so that the resultant I_p - E_g characteristic may have a longer straight portion, greater power output and good symmetry may be expected even with high-percentage modulated radio-frequency waves and high peak voltages.

5.9. Grid-leak versus Power Detection.—Although it is possible to obtain linear detection by carefully adjusting the grid-condenser and grid-leak values, it is difficult thus to obtain good fidelity with the grid-leak detection method owing to the high value of R_p , particularly when functioning into reactive load impedances.

This form of detection is also undesirable in the reception of high-percentage modulated radio-frequency signals because the second-harmonic content of the modulated frequency will be greatly amplified owing to the square-law output of this detector. The second harmonic of the modulation frequency present in the plate circuit, therefore, will be equal to $\frac{1}{4}m$, where m is the modulation percentage of the received carrier frequency. In other words, considerable distortion will result when receiving high-percentage modulated signals because the relation between the modulated radio-frequency input and the audio-frequency output is not a linear reproduction of the signal-wave shape.

However, in view of the low plate voltage used and the resultant high R_p , the grid-leak type of detector is desirable where a high degree of sensitivity is required.

The power detector, on the other hand, although not nearly so sensitive as the grid-leak detector, will produce superior fidelity of the demodulated signal owing to its ability to obtain a better degree of linearity.

Furthermore, the power detector, owing to its lower sensitivity compared with the grid detector, permits less critical filtering of the succeeding audio-frequency circuits and also greatly reduces the possibility of microphonic amplification generally referred to as *singing*.

5.10. The Vacuum-tube Amplifier.—*a. The principles of the vacuum tube as an amplifier* of radio-frequency or audio-frequency currents are the same since both primarily amplify alternating-current voltages through the grid action of the tube affecting the space charge. The only difference is that in the audio-frequency amplifier the voltage of the input frequency ranges between approximately 16 and 15,000 cycles, while in the radio-frequency amplifier the input-voltage frequencies range from 20,000 to 100,000,000 cycles and higher.

There are certain important fundamentals, however, which are applicable to both audio- and radio-frequency amplifiers. Both systems are primarily energy-transferring devices in which the voltage or power of one circuit is transferred to a second circuit. In radio-frequency receiving circuits the energy transfer from one circuit to another is generally in terms of voltage amplification, since the vacuum tube is primarily a voltage-amplifying device. The same holds true in audio-frequency receiving systems with the exception of the final amplifier stage where the energy transfer is generally one of power.

In order that the operation of the vacuum tube as either a voltage or a power amplifier may be clearly understood, the fundamental picture of the generator functioning into a load must again be applied.

Figure 5-7 illustrates the equivalent of a vacuum tube in a generator circuit. Units R_p and AC represent the vacuum tube as a generator unit. R_o and Z_o represent the external load or coupling unit into which the generator functions.

Although the grid is not shown, it is apparent that the generator symbol of the collector rings represents the operating condition of the tube which takes place during the period in which input voltages are applied to the grid. In other words, the generator, or plate circuit, may be visualized as being idle during the period in which no voltage impulses are received by the grid.

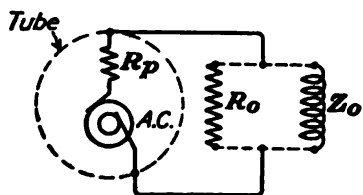


FIG. 5-7.—Equivalent vacuum-tube generator circuit.

Now, since it has been shown that the maximum power from a generator can only be absorbed by a load if it is matched to the generator resistance or impedance, then the amount of energy that can be transferred from the plate circuit of a vacuum tube to its load must depend primarily upon the proper

adjustment of the load impedance R_o or Z_o . Non-reactive loads containing neither inductance nor capacity are merely indicated R_o . Since most radio- and audio-frequency circuits contain reactive loads, the symbol Z_o is generally used.

Hence it may readily be seen that the total amplifying property of a vacuum tube will be dependent upon several factors, namely:

1. The amount of signal voltage impressed upon the grid of the tube, E_g .
2. The amplification constant of the tube, μ .
3. The relationship of the load impedance to the plate resistance of the tube.

Perhaps one of the most important fundamental considerations in viewing the operation of the vacuum tube is to assume a signal e.m.f. E_g to be impressed upon the grid. This should be visualized as an e.m.f. μE_g acting in the plate circuit with which the tube resistance R_p and the load R_o or Z_o are in series.

This fundamental picture is illustrated in Fig. 5-9 in which the generator symbol represents the acting voltage of the tube μE_g working into R_p and Z_o . R_p is the plate resistance of the tube and Z_o is the impedance looking into the primary of the transformer.

Now since the voltage across the load impedance is primarily due to the input or signal voltages E_g , applied to the grid, the alternating current I_p in the plate circuit must be directly related to this voltage. Hence,

$$I_p = \frac{\mu \times E_g}{R_p + Z_o} \quad (2)$$

Therefore, the voltage or potential difference across the load impedance must be

$$E_o = \frac{\mu \times E_g \times Z_o}{R_p + Z_o} \quad (3)$$

The maximum voltage, therefore, will be built up across a load when the load impedance Z_o is infinite with respect to the tube plate resistance.

b. Complexities.—There are, however, many complexities which enter into the functions just described, particularly when the load impedance Z_o is reactive. This may be readily seen if we refer to the alternating-current engineering principle in which it is shown that the impedance if positively reactive (inductive) varies directly with the frequency and if negatively reactive (capacitive) varies inversely with the frequency. If, therefore, the external load of Fig. 5-7 is inductive, the ratio of the

load impedance to the tube plate resistance will be a variable quantity and the output power or energy developed across the load impedance will also be dependent upon the frequency. In other words, high voltages will be developed across Z_o when the frequencies are high and low voltages when the frequencies are low.

Fortunately, however, if the load impedance is designed to have at least the same value as the plate resistance R_p at the lowest frequency that is to be amplified across Z_o , then the higher frequencies will be properly taken care of since they develop a larger voltage across the load due to the increase in the reactance X_L with the frequency. It has been found that a little over 85 per cent of the energy developed in the tube can be transferred or built up across a definite load impedance if the value of that load in ohms is approximately three times the plate resistance of the tube. Hence, if the load impedance is adjusted to give a maximum transfer at the lowest frequency to be received, a fairly flat output response may be expected over a band of frequencies.

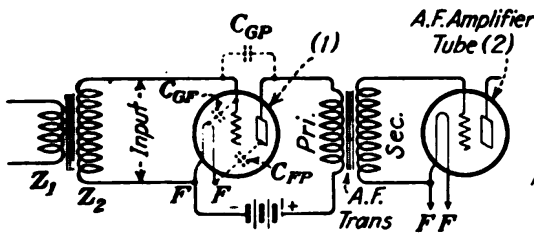


FIG. 5-8.—Transformer-coupled audio amplifier.

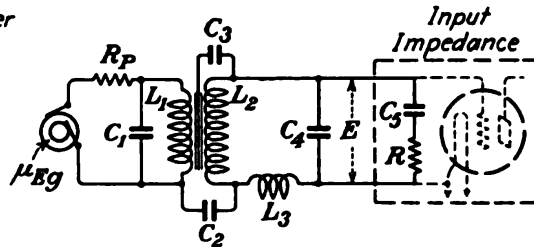


FIG. 5-9.—Equivalent circuit to Fig. 5-8.

If the load is inductive, as in the case of the audio-frequency transformer, the primary winding Z_o should contain a large value of inductance L to insure a maximum transfer of energy at the low audio frequencies below 100 cycles, thereby enabling a good audio-frequency response to be secured over the entire audible band, 30 to 10,000 cycles. There are, however, many other difficulties which arise in the audio-frequency transformer which limit the frequency response, particularly that of the distributed capacity in the windings.

c. Transformer-coupled Audio Amplifier.—Figure 5-8 illustrates a transformer-coupled audio-frequency amplifier circuit and its electrical equivalent Fig. 5-9. C_1 and C_4 represent the distributed capacity between the turns of the primary winding and the secondary winding, respectively. C_2 is the capacity existing between the two windings, C_3 is the capacity between the inner winding and the magnetic core, and L_3 represents the magnetic-leakage reactance. Although the distributed capacities may be kept extremely low by the proper design of the transformer, it is quite apparent that the higher range of audio frequencies will be by-passed because of the decrease in the circuit reactance at these frequencies.

Assuming that Figs. 5-8 and 5-9 represent two amplifier tubes coupled together by an audio-frequency transformer, then μE_g represents the voltage generated in the plate circuit of the first tube, R_p represents its plate resistance (also called *plate impedance*), and E is the voltage applied to the grid of the succeeding tube. Now, the secondary

voltage E must be equal to the voltage across the primary winding multiplied by the ratio of the turns in the secondary. Hence, if the transformer has a ratio of 1:1 and the primary has a voltage of 1 volt built up across it, the transfer will represent an e.m.f. of 1 volt across the secondary. If the transformer ratio is 3:1 then the voltage induced in the secondary will be 3 volts.

Now, since it has been shown that the maximum power will be absorbed by the load when the impedance of the load is equal to that of the generator, it will be seen that the voltage built up across a reactive load impedance will vary with the frequency. Consequently, the power transfer will be a maximum when the load impedance matches the tube impedance at some one particular frequency. In other words, the impedance which is reflected into the primary circuit, so to speak, can be a match to the tube impedance at only one frequency. This is an ideal condition in a radio-frequency amplifying system in which only one frequency is to be amplified. Here the one frequency would produce the greatest voltage transfer, while frequencies above and below would have a decidedly falling-off characteristic.

For uniform amplification the voltage built up across the primary at each frequency should be very nearly the same over the entire audio-response range in order that a flat response may be obtained. Hence the design of the transformer must be such that there is no particular or sharply defined amplitude peak at one of the audio frequencies.

It has been brought out previously that as long as the primary impedance of the transformer is three to five times higher than the plate impedance of the tube, when considering the lowest frequency to be amplified, the response from this point up will be essentially flat over the lower and middle range of frequency. This condition is true because the tube can be considered (at any rate over the middle range of frequency) as working into the equivalent of an open circuit as far as alternating current is concerned and thus reproducing the same voltages independent of the frequency.

At the higher frequencies, the distributed capacity and leakage reactance of the transformer come into effect. A glance at Fig. 5-9 will show that the input of the tube is connected across a condenser which forms an element of a series resonant circuit consisting of L_3 and C_4 . Thus, there will be a voltage built up across C_4 , which represents the distributed capacity of the winding, and which is Q times the voltage impressed across the resonant circuit. The leakage reactance and distributed capacity form a resonant circuit at some high frequency, and as this frequency is approached the output of the transformer will rise to a peak and fall off very sharply after this point. If a peak is undesirable within the range of the circuit, it may be eliminated in a number of ways. The simplest method is to insert resistance in shunt to the secondary. Another method is to design the transformer so that the peak falls out of the useful range of the circuit. This peak may be employed to extend the useful range of the transformer-coupled circuit by adjusting the circuit components so that the peak compensates for the attenuation at high frequencies caused by shunt capacities.

In connection with the above, it will become apparent then that the input impedance of the tube used will have a great effect on the high-frequency response of the

transformer as the capacity C_s becomes part of the resonant circuit. Thus, the lower the input capacity of the tube across the transformer, the better the high-frequency response obtainable. For this reason, it is preferable to use a pentode rather than a triode at this point. The plate resistance of the tube feeding the transformer is also effectively in series with this resonant circuit, and thus variations in this plate resistance will cause variations in the height of the peak.

From the foregoing, it can be seen that the tubes preceding and following the transformer must be carefully chosen to work with it. Modification of the circuit characteristics at the high frequencies may be effected by placing a resistance across the secondary winding, which will lower the Q , or by adjusting the bias of the preceding tube, which will effectively alter its plate resistance.

d. Resistance-coupled Audio Amplifier.—In this type of amplifier the theoretical operation of the circuit is somewhat different from that just explained for the transformer-coupled amplifier. In the resistance-coupled amplifier the voltage amplification or gain is that produced by the tube only and requires the use of high- μ tubes to effect the desired amplification. The theory of operation and general design considerations follow:

The schematic diagram of a triode resistance-coupled amplifier is shown in Fig. 5-10(a). The resistance R_L is the load or coupling resistance, the condenser C_c is the coupling capacitance, the resistance R_{GL} is the grid resistor of the following tube; and C_P and C_G are the output and input capacities of the two tubes, respectively, including stray wiring capacities. The equivalent circuit is shown in Fig. 5-10(b).

Since the resistance-coupled amplifier is almost always a voltage amplifier, it is desirable that the load resistance be large in order to obtain maximum stage gain. Thus, values of R_L for triodes are usually in the order of 100,000 ohms. The grid-leak resistance should not shunt the load resistance appreciably and is, therefore, about 0.5 to 1 megohm.

In the middle range of frequencies to be applied, where the capacities C_P and C_G are negligibly small and the resistance of C_c is ineffective, the stage gain for triodes is given by the equation

$$\text{Gain} = \mu \frac{R}{R + R_P}$$

where $R = \frac{R_L R_{GL}}{R_L + R_{GL}}$, the parallel resistance of the plate load and the grid resistance.

At high frequencies it is necessary to take into account the shunting effects of C_P , C_G , and the gain will fall off as the impedance of the capacities becomes comparable with the resistances involved. From a consideration of the factors involved one finds the following ratio,

$$\frac{\text{Gain at high frequencies}}{\text{Gain in middle range}} = \frac{1}{\sqrt{1 + (R_{eq}/X_c)^2}} \quad (4)$$

where $R_{eq} = \frac{R_P R_L R_{GL}}{(R_P R_L) + (R_L R_{GL}) + (R_P R_{GL})}$,

(the resistances R_P , R_L , and R_{GL} are all in parallel) and $X_c = 1/2\pi fC_c$, where $C_c = C_P + C_G$, the total shunt capacitance. Thus the falling off of the gain at high frequencies is determined by the ratio of the resistance of the plate load, the grid leak, and the plate resistance, all in parallel, to the reactance of the shunt capacity. In triodes the plate resistance is relatively low, and this is the predominant factor in determining the equivalent resistance. Pentodes have a plate resistance in the order of a megohm, so that the other resistances become important in that case.

At low frequencies the increased reactance of the coupling condenser C_c serves to reduce the voltage across R_{GL} . The effect of this is given by the equation

$$\frac{\text{Gain at low frequencies}}{\text{Gain in middle range}} = \frac{1}{\sqrt{1 + (X_c/R_s)^2}} \quad (5)$$

where $X_c = 1/2\pi fC_c$, which equals the reactance of coupling condenser C_c .

$R_s = R_{GL} + \frac{R_L R_P}{R_L + R_P}$, which equals the resistance formed by the grid leak in series with the parallel combination of the plate and load resistances.

Thus the amount that the gain falls off at low frequencies depends on the ratio of the reactance of the coupling condenser to the resistance of the grid leak in series with the parallel combination of the load and plate resistances. In most cases the grid-leak resistance will be by far the larger, and the other two may be neglected. When $X_c = R_s$, the gain has fallen off to 0.707 of its mid-frequency value.

In the design of a resistance-coupled amplifier, therefore, several things are of prime importance. The grid leak R_{GL} should be as large as possible without permitting the small amount of grid current that flows, owing to random electrons striking the grid, to build up an appreciable bias voltage. The load resistance R_L should be large with respect to the plate resistance. The coupling condenser C_c should have a reactance equal to about half the resistance of the grid leak at the lowest frequency transmitted in order to keep the gain to 90 per cent of the mid-band gain. Care should be taken, however, not to make the coupling condenser C_c too large, or else low-frequency oscillations, or "motorboating," may result. With triodes the effect of shunt capacity over the audio range is generally negligible, since a shunt capacity of 50 mmf. has a reactance of 320,000 ohms at 10,000 cycles.

e. Impedance-coupled Amplifier.—In the impedance-coupled audio-frequency amplifier the circuit arrangements as shown in Fig. 5-11(a) are identical with those of the resistance-coupled amplifier with the exception that the plate load is reactive, Z_1 , instead of resistive, R_L [Fig. 5-10(a)]. A grid-leak resistance R_2 may be used as in the resistance-coupled amplifier, or a reactance leak Z_2 may be employed.

The theoretical operation of this amplifier in the plate-load circuit is identical with that of the primary winding of the audio-frequency transformer previously explained, with the exception that the load functions into a series-resonant circuit as illustrated in Fig. 5-11(b). It is seen that if an impedance Z_2 is used, the combination of C and Z_2 in series will be resonant at some audio frequency. If C and Z_2 are so chosen that they

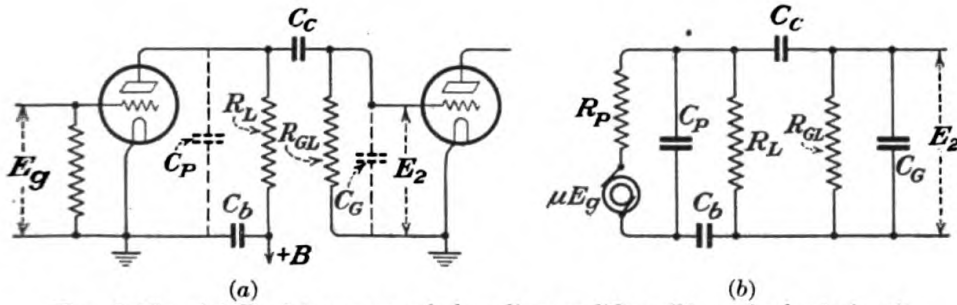


FIG. 5-10.—(a) Resistance-coupled audio amplifier; (b) equivalent circuit.

provide series resonance at say 100 cycles, a maximum voltage will be developed across G and K and in the vicinity of these frequencies. This will increase the response at the low end of the frequency spectrum.

The advantage of this type of amplifier is due to the low IR drop in the plate-load winding Z_1 as compared with the resistance-coupled type, and also to the high voltages that may be developed across Z_1 due to its reactive function.

In addition to its more limited frequency response, the disadvantage of this type of amplifier, compared with the resistance-coupled amplifier,

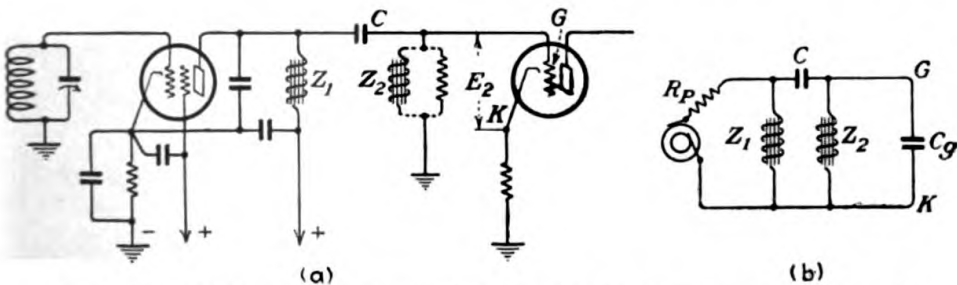


FIG. 5-11.—(a) Impedance-coupled audio amplifier; (b) equivalent circuit.

is the ability of the plate reactor to have e.m.fs. induced in its winding, thus producing undesired distortion and noises in the output. This disadvantage can be minimized by properly shielding the plate reactor against external fields.

Alternating-current engineering principles may readily be applied to Figs. 5-10(b) and 5-11(b) to determine the voltages developed across the component reactances and impedances.

5.11. Amplifier Distortion.—Amplifier distortion may be due to any one or all of the following conditions.

1. Excessive grid swing.
2. Improper grid bias.
3. Improper plate voltage.
4. Improper balancing in push-pull circuit.
5. Core saturation (audio-frequency transformer).
6. Improper load-impedance matching.
7. Improper reflected impedance from secondary circuits.
8. Improper filtering.
9. Self-oscillation.

Any one of these conditions may cause an alteration of the plate-current characteristic to resemble an unsymmetrical wave shape. Let us take, for example, the result when an insufficient grid bias is applied to the tube as shown in the plate-current characteristic illustrated in Fig. 5-12(a). If the bias is excessive, the plate-current shape will take the form of diagram (b). If the bias is correct, but the signal voltages are excessive, the plate-current shape will resemble Fig. 5-6(a). If the plate

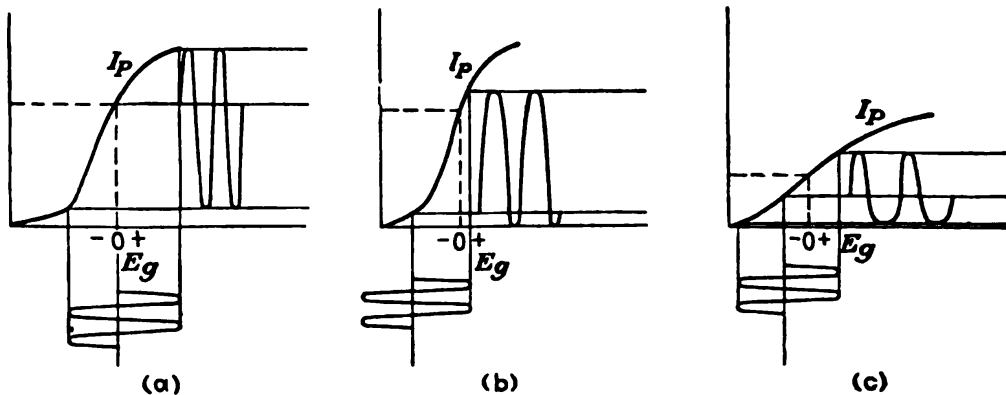


FIG. 5-12.—Plate-distortion characteristics.

and grid voltages are correct, but the load impedance is too low, the plate-current shape will resemble diagram (c), Fig. 5-12.

All of these conditions will produce distortion and the generation of harmonic frequencies.

The total distortion in any amplifier is practically entirely dependent upon the magnitude of the second and third harmonic-frequency components. Although it is possible to reduce these components by operating the tube into a load impedance relatively higher than that of the R_p of the tube itself as with the power triode, or about one-seventh with the power pentode, to obtain a fairly linear output, the harmonics can never actually be completely eliminated. Hence the only remedy would be to maintain the total harmonic-frequency contents of the amplifier as low as possible to obtain negligible distortion.

If the combined second and third harmonic-frequency energy components do not exceed more than 5 per cent of the fundamental frequency, a minimum degree of distortion may be expected. The total percentage

of harmonic distortion may be obtained by taking the vectorial addition of the second and third harmonics:

$$\text{Distortion} = \sqrt{H_2^2 + H_3^2} \quad (6)$$

The harmonics H_2 and H_3 are obtained by taking the ratios of the current components due to the normal-operating plate current and the changes in current due to the harmonics, thus

$$\text{Distortion} = \left[\frac{\frac{1}{2} \times (I_{\max} + I_{\min}) - I_{\text{normal}}}{I_{\max} - I_{\min}} \times 100 \right] \text{ per cent} \quad (7)$$

All higher harmonics are generally neglected since their amplitudes are too small to produce noticeable distortion.

It is possible practically to determine if excessive distortion is present due to harmonics in the power stages of an audio-frequency amplifier by inserting a milliammeter in the plate circuit. Since the generation of harmonics develops an asymmetrical condition in the plate circuit resembling rectification, the milliammeter will rise or decrease above its normal value while signal voltages are being received. Hence, if the plate milliammeter fluctuates above or below its normal value during reception, it is evident that rectification is taking place and distortion is present. Serious harmonic distortion will produce heavy fluctuation.¹

5.12. Power Amplification.—It has been explained that the vacuum tube functioning as a voltage amplifier delivers an output voltage dependent upon the product of the input voltage times the amplification factor of the tube. For example, if a potential of 1 volt is built up across the grid-filament circuit of a tube having an amplification factor of 10, the output voltage would be $E_o = \mu \times E_g = 10 \times 1 = 10$ volts.

Hence, if the input voltage is increased, the output voltage will increase in proportion. In the power amplifier, however, the output power is proportional to the square of the input voltage, consequently greater input voltages are required for effective operation. Now, if it is desired to convert the voltage into power in the output circuit of a vacuum tube, energy must be dissipated in the plate circuit by introducing a load which will be capable of absorbing power. If this load is too highly resistive or reactive, very little power can be absorbed and consequently very little energy can be transferred. Hence, if power is to be developed in the output circuit of a vacuum tube the load resistance or impedance must not be too high. Thus, if a low-resistance load circuit is required to absorb power, a vacuum tube of a low plate resistance must be used, as the maximum power will be transferred to the load impedance only when its ohmic resistance is equal to that of the tube impedance.

¹ A method for measuring harmonic distortion has been developed by C. G. SURTS, *Proc. I.R.E.*, Vol. 18, p. 178, January, 1930.

The maximum power output in watts developed across the load of a tube may thus readily be determined by the ratio

$$P_o = \frac{\mu^2 \times E_g^2 \times Z_o}{(R_p + Z_o)^2} \quad \text{watts} \quad (8)$$

where Z_o represents the output load resistance or impedance and E_g the input grid voltage developed across the grid-filament circuit of the tube.

Let us take for example a power tube such as the Western Electric 205E which has an amplification constant of 7 at 300 volts and a plate impedance R_p of 4,000 ohms. If an average input voltage of say 20 volts is applied to the grid, and the load impedance is made to match the tube impedance, the output power into the load impedance will be

$$P_o = \frac{49 \times 400 \times 4,000}{(4,000 + 4,000)^2} = 1.2 \text{ watts (approx.)}$$

If the load-impedance values in both the numerator and the denominator in the above example are changed to higher or lower values than the tube impedance, it may be clearly seen that this impedance mismatch will develop considerably less power in the load than under the matched impedance conditions. Thus it may once more be seen how the matching of tube impedances is essential where a maximum degree of power transfer is desired.

In high-quality audio-frequency amplifying systems, however, the matching of load and tube impedances may not be desirable because of the increased possibility of distortion, particularly if the load impedance is too low. This is due to the fact that, when the load impedance is too low, the straight portion of the I_p - E_g characteristic curve may be considerably shortened. Consequently, if fairly large input voltages are applied to the grid under these conditions the resultant plate-current variations may resemble a box type or an asymmetrical signal-wave shape as illustrated in Fig. 5-6. This will result in the production of a second-harmonic or double-frequency component supplemental to the original signal input. Hence, if this second-harmonic content is too large, serious distortion of the original signal-wave shape will occur. To prevent this, the load-impedance and operating characteristics must be carefully analyzed to obtain a *maximum undistorted* power output.

Now, if the load impedance is made greater than the tube impedance the output power developed across Z_o will also be considerably less as has been shown, but, on the other hand, it will tend to increase the length of the straight portion of the I_p - E_g characteristic curve. Hence, if the plate impedance is approximately twice the impedance of the tube, the maximum degree of undistorted power with a minimum second-harmonic content will be obtained. This condition will, however, not be entirely fulfilled unless the signal-input grid and bias voltages are also increased.

Tubes operating into matched impedances provide the greatest amount of power output, whereas tubes operating into higher load impedances develop less power but provide a greater linear characteristic. Hence, tubes operating into loads of twice their internal impedances provide a greater possibility of obtaining a symmetrical reproduction of the input signal voltage by the extension of the straight portion of the plate characteristic curve and thereby minimizing the degree of distortion of the incoming signal.

The maximum possible undistorted power output, when the load impedance is twice the tube impedance, may be obtained from the ratio

$$P_{\max} \text{ (undistorted)} = \frac{\mu^2 \times E_g^2}{8 \times R_p} \quad \text{watts} \quad (9)$$

Perhaps two of the most important factors in the design of power-amplifier systems to prevent distortion is, first, to design the load impedance so that the impedance at all times will remain higher than the tube impedance, particularly when the lowest audio frequency is being impressed across it. This will require a tube having a low plate resistance. Second, to maintain a value of grid bias which will at all times be greater than the maximum peak voltage of the signal swing. For example, if an incoming signal of 20 volts peak is applied to the grid-filament circuit of the tube, the negative grid-bias potential should not be less than -20 volts and preferably more.

If the signal swing exceeds the bias potential, a grid current will flow during the incoming positive peaks, and a *resultant* load is placed upon the plate circuit. This effect functions upon the I_p - E_g characteristic curve the same as decreasing the negative bias, because, when the grid draws current and an IZ drop takes place across the filament-grid circuit, it reduces the voltage built up across these two points. As soon as this takes place, the operating point on the curve is moved up toward the top portion of the characteristic, so that the incoming signal produces an asymmetrical plate-current¹ effect owing to the loss in the linearity of the curve. Thus it may be seen that if the operating point is moved upward on the I_p - E_g curve the impedance of the plate circuit will be lowered considerably.

5.13. Push-pull Amplification.—This form of amplification is also known as *balanced amplification* and refers to the distribution of voltages and currents in vacuum-tube grid and plate circuits. This method of amplification is generally used in radio- and audio-frequency power-output circuits to develop a symmetrical or balanced wave shape in the load circuits together with an increase of power output. Tubes connected in this manner also serve to reduce the generation of the undesirable second-harmonic frequency which is normally developed in single-tube output circuits, such as shown in Fig. 5-13, due to asymmetry resulting from improper circuit adjustments and characteristics.

It has previously been shown that the output circuit of any amplifier must reproduce symmetrically the grid voltages impressed upon the grid

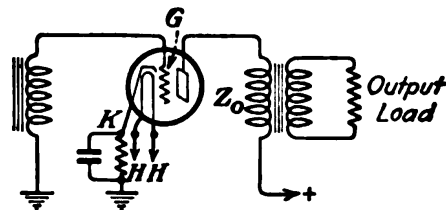


FIG. 5-13.—Single-tube audio amplifier.

¹ The term *asymmetrical* or *non-symmetrical* referred to in vacuum-tube circuits is used to express the lack of equal proportion between the positive and the negative halves of a voltage or current cycle.

so that the output-circuit variations conform with that of the input-signal shape.

We have seen that this plate symmetry can only be approached provided that the grid bias is so adjusted that the tube will operate at the



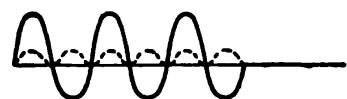
(a) Input voltage



(b) Plate current



(c) Effective I_P through Z_o .



(d) Second harmonic (dotted)



(e) Effective fundamental and harmonic plate current variation through Z_o .

FIG. 5-14.—Single-tube circuit fundamental and harmonic components.

center of the straight portion of the I_p - E_g characteristic curve. This is no assurance, however, that the output-wave shape will be a symmetrical reproduction of the signal on the grid since an excessive grid swing may drive the plate currents into the upper and lower curved portion of the I_p - E_g characteristic and produce a square-topped type of wave as previously explained. Furthermore, if the load impedance is too low, distortion will also result owing to the asymmetrical variations developed across the impedance. For example, let curve (a) in Fig. 5-14 represent an incoming wave developed across GK of a simple amplifier circuit, Fig. 5-13. If the grid bias is adjusted at the straight portion of the I_p - E_g curve, and no grid current is flowing, the plate-current curve will be that illustrated by the heavy curve in (b). In other words, the increase in plate current, when the grid is positive owing to the signal, will be relatively greater in amplitude than the decrease in plate current when the grid is negative owing to the signal.

Consequently, the signal will not be represented by a symmetrical variation in the plate circuit and distortion will result.

If the input transformer is so designed that the grid circuit is continually drawing some current, the output-wave shape may be more symmetrical as illustrated in (b) by the dotted curve. This is due to the fact that, when the grid current flows during the positive half of the input cycle, an IR drop takes place through the resistance of the secondary winding of the input transformer. Hence, the amplitude of the plate current during the positive peak will be reduced thereby producing a more symmetrical output in the plate circuit. However, since the grid circuit absorbs power under this condition, less amplification will be available in the output-load circuit Z_o in Fig. 5-13. It has been previously shown, however, that if distortion is due to a low plate-load impedance, it may be practically eliminated by raising Z_o to a value at least equal to that of the tube resistance, R_p . With a single tube, therefore, it is difficult to produce a symmetrical plate-current output unless

the signal e.m.fs. are kept very low and the plate-load resistance high with respect to the tube resistance. Hence, the ever present possibility of asymmetrical plate-current variations will produce a wave form in the plate circuit equal to twice that of the fundamental frequency. This is called the *second-harmonic frequency* and is illustrated by the dotted curve in (c). Obviously, the combining of the fundamental and harmonic frequencies through Z_o will produce distortion. This is one of the most

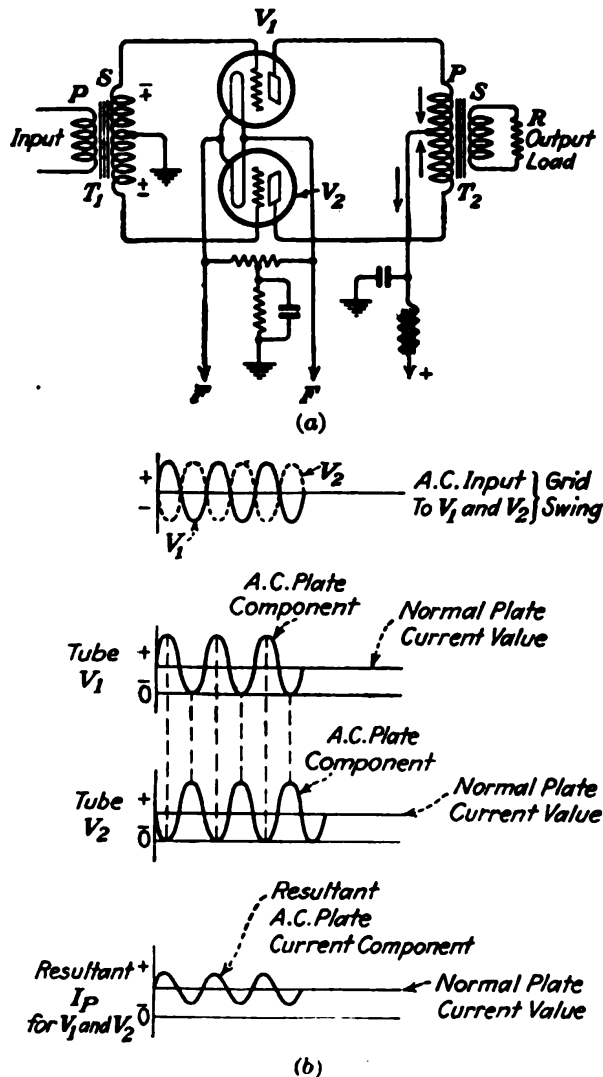


FIG. 5-15.—Push-pull amplifier: (a) circuit; (b) operating characteristics.

prevalent causes of distortion in single-tube amplifiers, particularly if large grid swings are applied.

In the push-pull or balanced amplifier it is possible to balance out this second-harmonic frequency by the output transformer windings so that the fundamental frequency alone will be present in the output secondary winding or load circuit. How this is accomplished will be explained in the following analysis of a balanced amplifier.

Theory of the Push-pull Amplifier.—Figure 5-15(a) and (b) illustrates the conventional circuit arrangement of a push-pull amplifier and wave characteristics as used in a class A audio-frequency power-amplifier system.

If an audio-frequency e.m.f. is developed across the primary winding of the input transformer T_1 , a voltage will be induced across the secondary winding of the transformer in accordance with the fundamental laws of induction previously explained. Consequently, during each half of the cycle the two grids are of opposite polarities; but, since this polarity is constantly changing, the two grids are continually alternating in polarity with respect to each other. Thus when the grid of V_1 is positive the grid of V_2 will be negative and vice versa.

Now, let us assume an incoming audio-frequency signal of 1,000 cycles is being developed across the secondary winding S of the input transformer T_1 . This signal will apply to the grids of both tubes an e.m.f. of equal magnitude but with a phase difference of 180 degrees. That is to say, the voltages developed on both of the grids will be 180 degrees out of phase with each other. Now, since the grid of one tube will be positive and that of the other tube negative during each cycle, the alternating plate voltages in the primary winding of the output transformer will also be 180 degrees out of phase with each other. Consequently, the resultant plate-current components in the two halves of the primary winding will also be 180 degrees out of phase with each other. However, the magnitude of the current flow in each half will be of a different value, since the plate-current flow in the primary half of V_1 will be higher than that of V_2 , if the grid voltage at this instant is positive on V_1 . Then, as the cycle reverses to make the grid of V_2 positive and of V_1 negative, the plate-current magnitudes will be such that the amplitude in the plate half of V_2 will be greater than that of V_1 . Now, since the currents in the two halves are in opposite directions, it would seem that the magnetic fields created by them would cancel each other. This condition would prevail if the currents in each half of the winding were of equal magnitude, but, owing to the fact that the current flow in each half is dependent upon the polarity of the grid potential of each tube, it is apparent that the plate current in V_1 will be greater than that in V_2 during the instant when the grid of the former is positive and that of the latter negative. Hence, the current through the primary winding of T_2 will be the difference between the current flowing in the primary winding of V_1 and V_2 . In other words, a signal voltage of 1,000 cycles will be developed across the primary winding of the output transformer.

Now, if the secondary winding of the output transformer is open so that no current and magnetic field are produced, no reaction will take place upon the primary winding of T_2 . Under this condition the second harmonic-frequency current component in both halves of the primary winding will be in opposite directions causing the magnetic fields to oppose and cancel each other. The fundamental frequency, on the other hand, will be increased since the magnetic fields due to it are in the same direction. These conditions are due to the fact that the currents in the plate-circuit halves, due to the harmonic frequency, are in phase, while those due to the fundamental frequency are 180 degrees out of phase with each other. Now, if the secondary winding is closed by a load resistance R to represent a power-operated device such as a loud-speaker or telephone line, the voltages developed across the winding will cause a current of an alternating character to circulate through it at a frequency depending upon the arrangement of the secondary windings.

For example, if the input frequency of 1,000 cycles is producing plate variations in the two halves of the primary winding, the e.m.f. developed across the secondary winding will depend upon the manner in which the secondary is wound. That is to say, if the secondary winding forms a continuous coil as illustrated in Fig. 5-16(a), the e.m.f. developed across it will be proportional to the difference between the plate currents in the primary halves. This is due to the fact that the relationship of the

secondary winding to the two halves of the primary windings is such that the two halves of the secondary will have e.m.fs. developed in opposition to each other, since the current in the primary halves are 180 degrees out of phase. Thus the e.m.f. and resulting current flowing in the load circuit will be the proportionate difference between the two e.m.fs. of the two plate-current components. During each half cycle, therefore, the e.m.f. developed across the secondary will resemble amplitudes of an alternating character, such as illustrated in Fig. 5-17. Thus the original signal

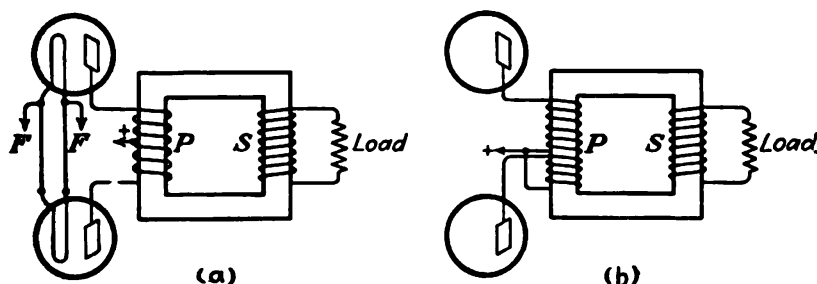


FIG. 5-16.—Push-pull circuits: (a) circuit for second-harmonic elimination; (b) frequency-doubling circuit.

frequency of 1,000 cycles will alone be developed across the secondary winding, since the harmonic has been previously canceled out in the two halves of the primary winding. Hence, in a balanced or push-pull arrangement, the output e.m.f. will approach the ideally symmetrical output even though each half of the cycle is asymmetrical in character as illustrated in Fig. 5-17.

Now, if the secondary winding is arranged, as in Fig. 5-16(b), so that the two e.m.fs., due to the two plate-current variations, are additively developed across the secondary, an e.m.f. of twice that of the 1,000-cycle fundamental frequency will be developed. In other words, the latter arrangement will cause the magnetic fields of

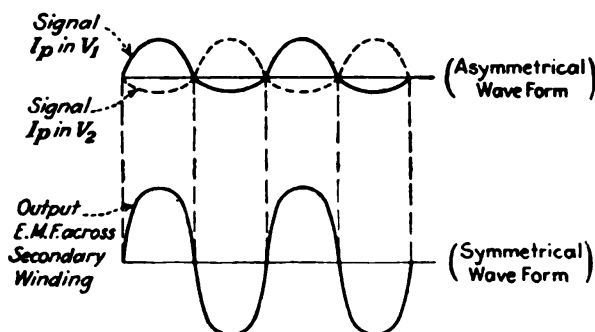


FIG. 5-17.—Symmetrical wave form produced by a class A push-pull amplifier.

the 1,000-cycle frequency to cancel owing to their phase opposition; while the magnetic fields due to the harmonic frequency will be additive because they are in phase. The balanced amplifier is then functioning as a frequency-doubling device.

In addition to its ability to balance out the inherently generated second-harmonic frequency and produce a symmetrical signal output, the push-pull amplifier also possesses several other advantageous features. These features are summarized as follows:

a. The power output of a push-pull amplifier is greater than twice that of a single tube for the same distortion content owing to the cancellation of the even harmonics in the push-pull circuit.

b. Owing to the fact that the direct-current plate components are always in opposite directions, the resulting magnetic fields cancel. In audio-frequency output

transformers this is a highly desirable condition because it prevents the magnetic saturation of the iron core by the normal direct-current plate-current components.

c. The possibility of a hum frequency due to the ripples developed in the power-supply system is practically eliminated, since these ripples will be in phase in the respective halves of the primary winding of the output transformer and will therefore cancel each other.

5.14. Grid and Plate Filtration.—Another important consideration in the design of all types of amplifying systems, including both radio- and audio-frequency amplifiers, is the proper isolation between coupled stages to prevent interstage coupling and reactions. This is particularly important in high-gain amplifiers where the possibility of common coupling (common impedance) is prevalent owing to the use of a single power supply for all stages. Common coupling may produce serious

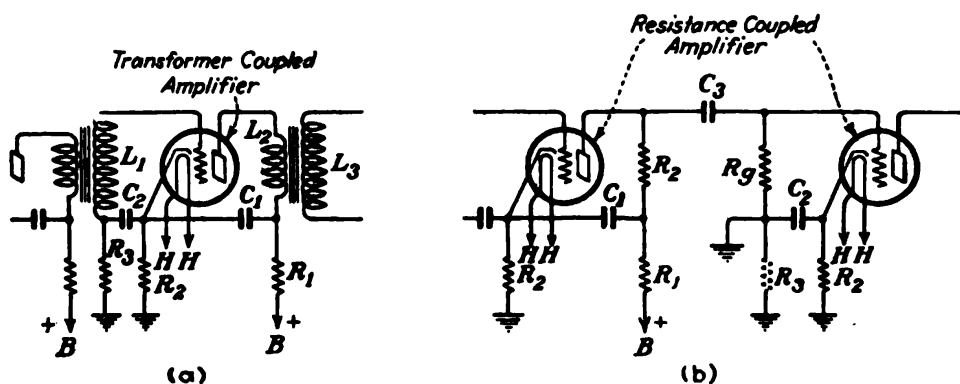


FIG. 5-18.—Grid- and plate-filtering circuits.

distortion in amplifiers owing to the circuit reactions causing variations of grid voltages at different frequencies, thereby distorting the signal-wave shape. In many cases the reactions may be great enough to produce whistling and howling, particularly in high-gain radio- and audio-frequency amplifiers.

Figure 5-18(a) and (b) illustrates a typical audio-frequency amplifier using grid- and plate-filtering systems. The plate-filter system consists of the resistance R_1 and the condenser C_1 ; and the grid filter, diagram (a), of the resistance R_3 and the condenser C_2 .

The theoretical function of the filter circuit may be more readily understood by referring to the fundamental circuit in Fig. 5-19. Here the alternating-current generator in series with the plate supply represents the irregularities (ripple) in the plate circuit, caused by the power supply. If at 120 cycles the condenser C has a reactance of 1,000 ohms, the impedance of the combination will be about one-third that of the resistor alone, and the resultant voltage drop across it will be correspondingly less. As no direct-current flows through the 100,000-ohm resistor in series with the grid, there is no direct-current voltage drop across it. Thus, it has no effect on the bias. It will be noted that the high resistance and the condenser form a voltage-dividing circuit for the alternating current appearing across the biasing resistor. Only those portions of the alternating-current and audio-frequency voltages appearing across the condenser C will be impressed on the grid of the tube. As the reactance of

the condenser at 120 cycles is 1,000 ohms, compared with the 100,000 ohms resistance, roughly only one one-thousandth of the alternating-current or ripple voltage appearing across the biasing resistor will reach the grid.

In Fig. 5-20 is shown the adaptation of this circuit as usually used for the *input* tube of a high-gain system. This point is, of course, the most critical in regard to hum. The first filter C_1 , R_1 reduces the alternating-current to one one-thousandth of its original value. This e.m.f., which appears across condenser C_1 , is impressed on the second and similar filter circuit C_2 , R_2 and is further reduced by the same proportion; so the final reduction is 1,000,000:1. As no grid current is allowed to flow, the bias voltage is unaffected by the high resistors.

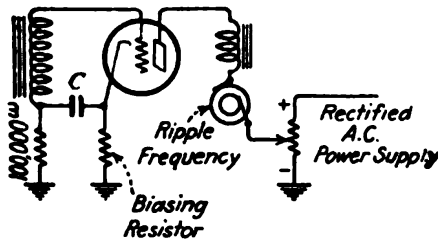


FIG. 5-19.—Illustration of principle of grid-filtering circuit.

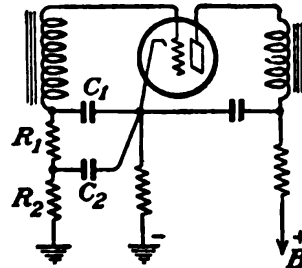


FIG. 5-20.—Grid-filtering circuit for high-gain audio-input circuits.

The complete stabilization that may be obtained in amplifiers using these method has resulted in its wide adoption among amplifier-designing engineers.

Note: For further discussion on plate filters see Sec. 3.19 on Radio-frequency Chokes.

5.15. The Diode Detector.—Figure 5-21 illustrates the circuit of a simple two-element rectifying system using the cathode-heater type of tube in the diode circuit. The cathode and the plate are tied together to form one element, and both are connected to ground potential. No plate voltage is used in order that the rectified-signal group may be entirely dependent upon the signal-wave shape itself.

Let us assume that an incoming-signal frequency of a modulated character is amplified through a number of radio-frequency amplifier stages and applied across the tuned circuit XY when this circuit is properly adjusted to resonance with the incoming frequency. Since the incoming signal is of a damped character, its amplitude will vary in accordance with the modulated frequency as illustrated in Fig. 5-22(a). However, owing to the rectifying action of the diode, the wave shape across C_1R_1 and R_2 will be of an asymmetrical characteristic, such as illustrated in Fig. 5-22(b). The reason for this asymmetry is as follows.

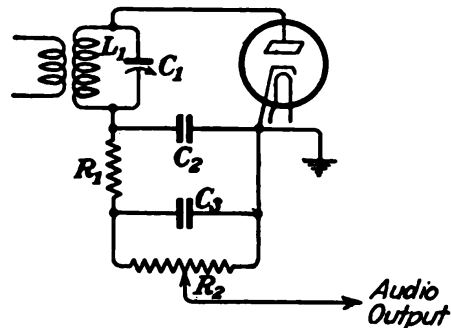


FIG. 5-21.—Diode-detector.

When the positive halves of the incoming cycle are applied to the grid, electrons will be attracted to it and will flow in the direction of the arrows through L_1 , R_1 , and R_2 , returning to the cathode and completing the circuit. The flow of electrons through the resistance R_2 builds up an

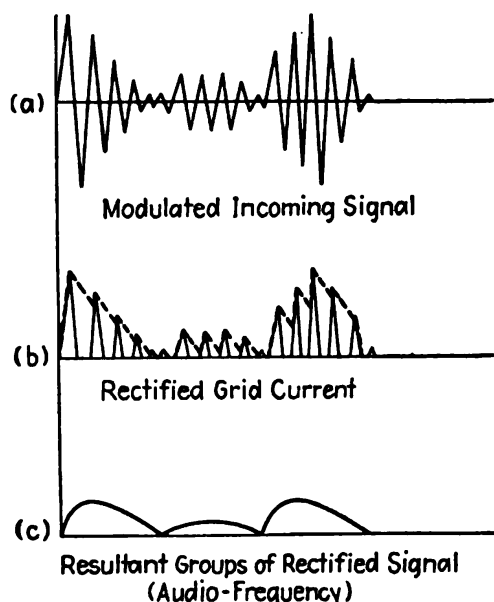


FIG. 5-22.—Incoming and rectified wave characteristics.

e.m.f. across it. This voltage charges the condenser C_2 . When the signal reverses, no signal flows through the diode, and the charge on condenser C_2 starts to leak off through R_1 and R_2 . On succeeding radio-frequency cycles this process is repeated, giving a resultant audio-voltage wave shown as the dotted line in Fig. 5-22(b).

There is still an appreciable radio-frequency component to the audio signal, represented by the saw-toothed character of the voltage on C_2 . This is eliminated by the filtering action of the combination R_1C_3 . Greater audio voltages could be obtained if the output wave were taken from condenser C_2 directly, but the

desirability of eliminating all the radio-frequency component requires the loss due to the divider action of R_2 and R_3 .

The rectified low-frequency voltages may then be suitably amplified by feeding them to an audio-frequency voltage-amplifying system. These voltages are taken off at the points A , B of the potentiometer R_2 and are regulated in accordance with the volume required.

The audio frequencies are fed to the first amplifying tube through the medium of the coupling condenser C_4 . Hence, any audio voltages developed at the points A , B will be applied directly across the GK elements of the amplifier tube.

The diode system of detection unquestionably provides the finest form of rectification with negligible distortion. The disadvantage is primarily in the low amplification secured, as compared with the triode type of rectifier. If, however, sufficient radio-frequency amplification is provided ahead of the diode detector, large signal voltages may be developed, which will insure a desirable audio-frequency output.

5.16. The Automatic Volume Control.—Figure 5-23 illustrates a vacuum-tube circuit in which the incoming signal volume is so controlled that the overall gain or signal level is practically constant. This eliminates excessive blasting and overloading at the high incoming peak voltages and serves to improve the fidelity of reception. The operation

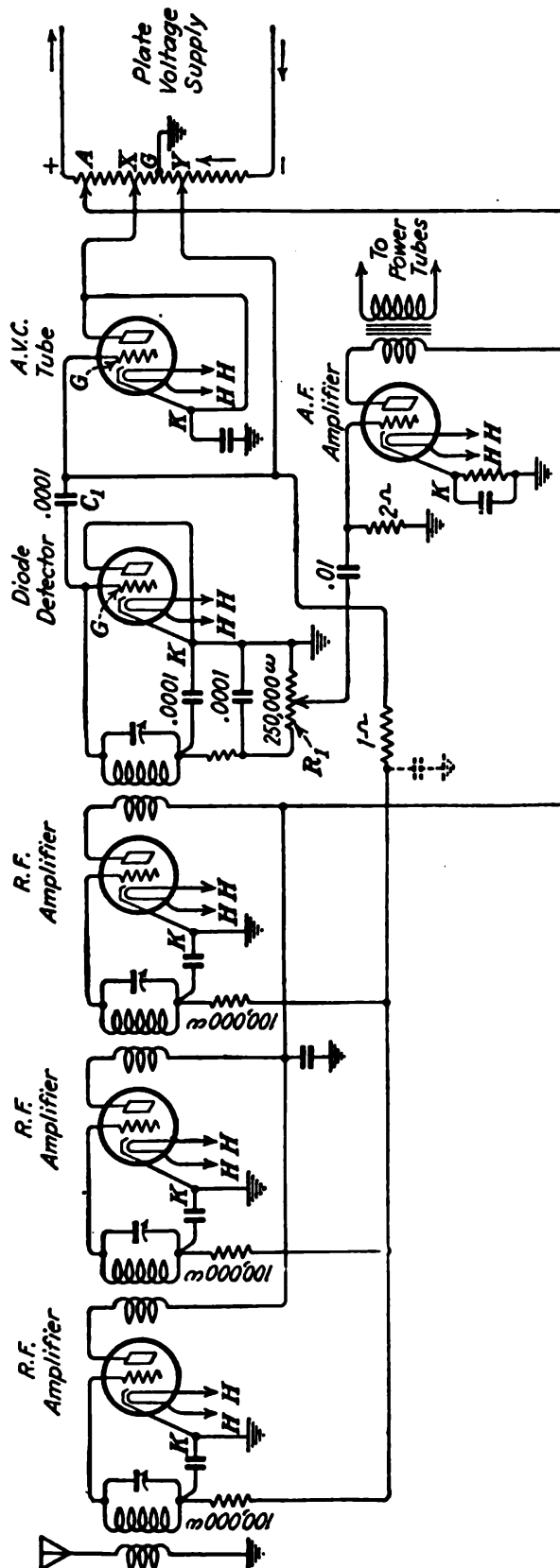


Fig. 5-23.—Delayed-action AVC circuit.

of the tube in producing this function is called the *automatic-volume-control*, or *AVC*, circuit.

a. *The theoretical operation* of all *AVC* circuits is based upon the biasing control of the radio-frequency amplifier grids. That is to say, when incoming signal voltages are amplified through a number of radio-frequency stages the normal negative grid bias is reinforced by an additional negative bias which increases in direct proportion with the increase of the signal voltage. As the signal voltage increases, the grid bias is automatically increased to the point at which the signals are actually "throttled." By the careful adjustments of the *AVC* circuit constants, all excessive signal peaks may be kept down to a desirable level and the possibility of overloading and distortion thereby greatly minimized.

The theoretical operation of the automatic control is as follows:

Before a signal is applied to the grid of the first radio-frequency tube, it is assumed that all of the normal plate and grid-bias voltages are applied. When this is the condition, the plate voltages for all the tubes are obtained between the points *A* and *G* on the voltage divider. The normal bias voltage is obtained between the points *G* and *Y* of the voltage divider owing to the fact that the point *G* is the ground and all of the radio-frequency tubes have their respective cathodes connected to this point. Thus, since all of the grid-return leads connect to a point which is more negative than that of the cathode, namely, the point *Y*, the potential difference existing between these two points is the normal grid bias applied to all of the radio-frequency grids.

When a signal is applied to the grid of the first radio-frequency tube and amplified through the successive radio-frequency stages, a fairly large signal voltage may be developed across the input of the diode-detector circuit at the points *G*, *K*. This results in a rectifying action of the incoming modulated frequency in accordance with the diode theory of detection previously explained. The rectified-audio-frequency groups are then applied to the grid of the audio-frequency amplifier tube through the volume-control potentiometer *R*₁ and amplified at an audio frequency.

However, since the radio-frequency signal voltages developed across *G*, *K* of the detector tube are also applied across *G*, *K* of the *AVC* tube through the coupling condenser *C*₁, any voltage developed across the *AVC* tube will result in an increase in the potential across the voltage divider at the points *X*, *Y*. Hence, if the normal voltage existing between these two points is supplemented by an increased voltage, a current will flow in the *AVC* tube circuit and the point *Y* will be made still more negative than before, and an increased negative bias will result on the grids of all the radio-frequency tubes.

It may thus be readily seen that excessive signal voltages will raise the grid bias on the radio-frequency tubes through the *AVC* action, and thereby there will be maintained a fairly even signal output, free from overloading and consequent distortion at high signal peaks.

b. *The most effective system of AVC action*, generally known as *delayed AVC*, is one in which the control does not become operative until the signal voltage exceeds that of the divider at the points *X*, *Y*. That is to say, no current will flow in the *AVC* tube circuit until a voltage greater than that existing at these two points is developed. In this system the sensitivity of the receiver is greatly improved over the ordinary *AVC*

circuit particularly on feeble signal voltages. In addition, the signal level is maintained at a much higher ratio with respect to the noise level inherent in high-gain receivers.

Noise suppression is, however, an independent action and is generally obtained by the use of a special tube possessing characteristics adaptable to this function.

c. The AVC Time Constant.—If a condenser is charged or discharged through a resistance, the time in seconds required for the voltage to grow to 63.2 per cent of its final value or decay to 36.8 per cent of its original value is found to be the product of the resistance in ohms and the capacitance in farads and is called the *time constant* of the circuit. Thus,

$$T = \frac{CR}{10^6} \quad (10)$$

NOTE: Where C is expressed in microfarads.

For example, if a condenser of 0.01 mf. is charged and then connected across a resistance of 100,000 ohms, the discharge rate through the resistance will be $0.01 \times 100,000/1,000,000$, or 0.001 sec.

This is an important factor in efficient AVC systems since the delayed action maintains maximum sensitivity, provides maximum power output, and minimizes distortion due to excessive signal swing. In other words, the delay action provides automatic control only if the signal value exceeds a certain value, thereby enabling weak signals to be developed across the detector input without the piling-up effect of grid bias and the resultant decrease in circuit sensitivity. Hence, only the powerful signals will be controlled by the delayed action, thus maintaining an average signal level without overloading.

The value of the time-delay constant for ideal performance should be between 0.04 and 0.09 sec. and should not be allowed to exceed the latter value. If the constant is excessive, it will be impossible to provide automatic compensation on rapidly fading signals, since the AVC voltage should be able to follow and compensate all noticeable changes in signal level. Furthermore, much more difficulty will be experienced in tuning the circuit to resonance. An excessive time constant may readily be detected by adjusting the circuit to resonance with a powerful signal and with the volume-control set at the maximum gain position. If the circuit is quickly detuned by moving the tuning condensers to an off-resonance position, the background noise in the receiver due to high-gain amplification should appear immediately. If a QAVC tube is used, it should be opened when making this test. If the noise level builds up gradually, it is a definite indication that the time delay is excessive.

An explanation of time-delay action may be clearly understood by referring to Fig. 5-24. When an incoming signal is developed across the input of the diode-detec-

tor tube the asymmetrical or rectified variations will pass in direct-current pulses through the two resistances R_1 and R_2 . The rectified variations through R_1 are used to develop the audio-frequency voltages to be fed to the amplifier circuit in general conformity to the theory of detection and audio-frequency amplification previously explained. However, since two complete diodes are used, the one connected to the resistance R_2 will also pass rectified audio-frequency variations. These latter variations will be used to produce the automatic control action desired. Thus it may readily be seen that, as an incoming radio-frequency signal is rectified, a constant direct-current voltage will be developed across the resistance R_2 of a value depending primarily upon the amplitude of the signal voltage and the value of the resistance R_2 . Hence, the direct-current voltage across R_2 will charge the condensers C_1 , C_2 , and C to the same voltage as that being developed across R_2 . Consequently, if the incoming signal should possess a fading characteristic, the voltage developed across R_2 , while the signal developed is strong, will charge the condensers C_1 and C_2 and establish an increased bias on the two radio-frequency amplifier grids. However, if the signal

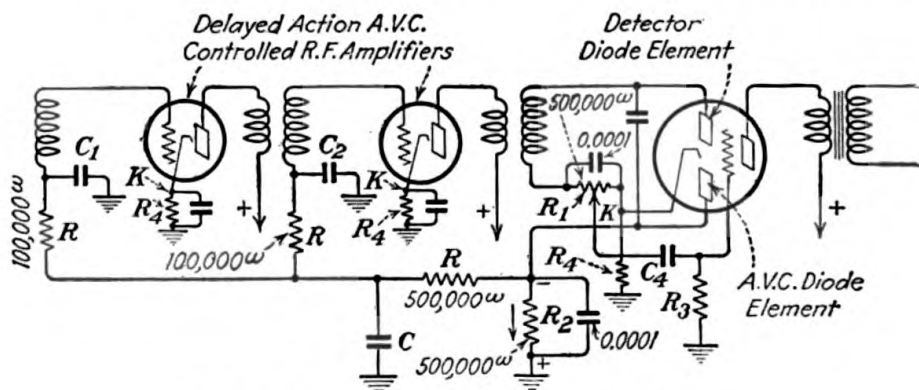


FIG. 5-24.—Diode detector and AVC circuit.

intensity should suddenly drop due to a fading condition and the condensers C_1 and C_2 should have not discharged sufficiently through R , R , R , and R_2 to release the throttling bias, the fading signal will not be compensated for and the automatic gain-control action will be lost. In other words, it is imperative for the condensers C_1 and C_2 to discharge fairly rapidly when the signal volume diminishes, to insure maximum sensitivity.

Although the main purpose of the resistances R_1 , R_2 , and R_3 and the condensers C , C_1 , and C_2 is for the purpose of grid filtration, that is, to prevent feed-back reactions between the various stages due to the common coupling connections, it is also important that the values of these condensers and resistances shall not impair the desired AVC action, particularly with fading signals. Hence, if the resistance values are made sufficiently large to prevent circuit reactions, yet not large enough to affect the circuit sensitivity owing to too much time lag, the operation of the circuit may be considered ideal for both sensitivity and automatic control. It is for this reason that the values of R and C must be properly proportioned in the grid-return circuit so that the time lag will not exceed the maximum 0.09-sec. value.

For example, let us assume that C , C_1 , and C_2 have a capacity of 0.015 mf. each and that the three filtering resistances R and the developing resistance R_2 have respective values of 100,000, 100,000, 500,000, and 500,000 ohms. This will introduce a total resistance of 1,050,000 ohms across the three condensers. The average time constant for this combination will be

$$T = \frac{CR}{10^6} = \frac{0.045 \times 1,050,000}{1,000,000} = 0.047 \text{ sec.}$$

Since this value is within the required range, satisfactory delay action should be obtained. It is important of course that the value of C and R for each grid filter be so apportioned that the radio-frequency voltage variations developed across R_1 will be dropped down to a negligible value across C_1 and C_2 .

5.17. Noise-suppression Circuit.—Noise-suppression control between assigned frequencies as effected by a tube and circuit arrangement designed for this purpose is commonly known as a *QAVC squelch*, or *Q-tube circuit*.

Figure 5-25 illustrates a practical arrangement of a noise-suppression circuit using a diode detector and a QAVC tube. In this particular

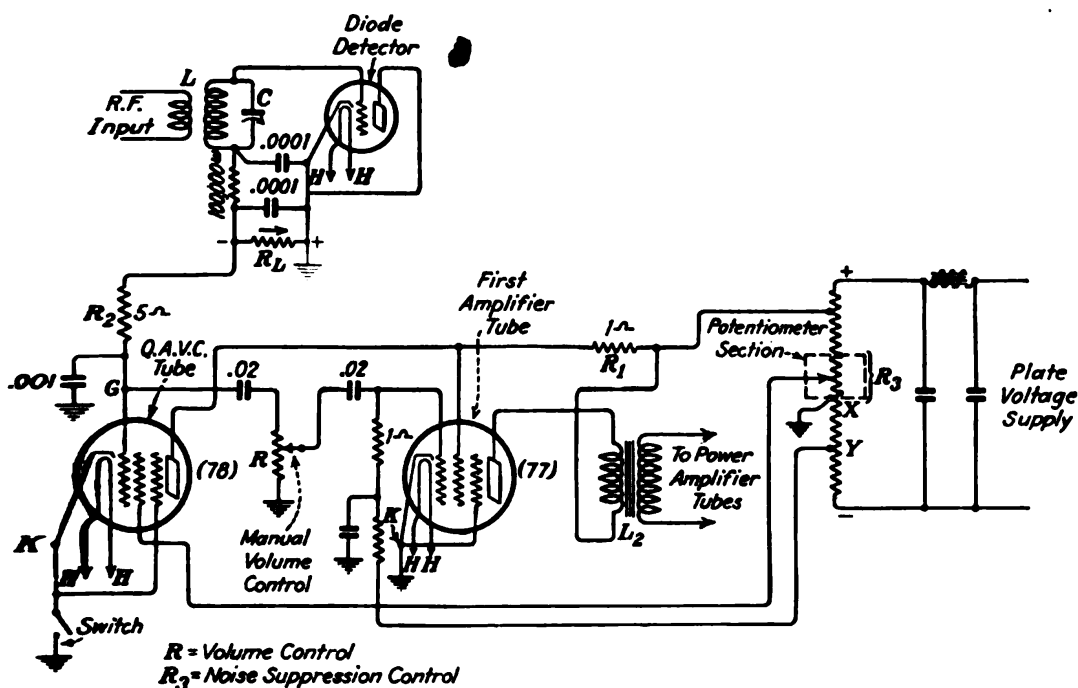


FIG. 5-25.—Intercarrier noise-suppression circuit.

system the first audio-frequency tube is automatically controlled, instead of controlling the radio-frequency amplifier as is done in the *AVC* circuit.

The use of this arrangement serves to reduce the inherent noises in modern high-gain receivers between the resonant adjustments of various stations. This is commonly known as interstation noise suppression.

The operation of this circuit, shown in Fig. 5-25, is as follows.

During the period in which no signals are being received and when no radio-frequency voltages are built up across the tuned circuit LC , the normal plate, screen, and bias voltages are applied to the two triple-grid tubes 78 and 77.

The plate of the 78 and the screen grid of the 77 tubes are tied together and receive their respective voltages from the voltage-divider system through the resistor R_1 . The normal grid bias for the 77 first-audio tube is supplied by the section of the voltage-divider system between the points X and Y .

When no signal voltages are applied across the tuned circuit LC , no voltage will be present on the control grid of the 78 QAVC tube. This results in a large increase of

the plate current for this tube owing to the large reduction in space charge because of the positively charged screen. At the same time this large plate current must be flowing through the resistance R_1 , resulting in a voltage drop across it. Now, since the screen of the audio-frequency amplifier tube 77 receives its voltage from this resistance, the IR drop across it will reduce this screen voltage. The design of this particular tube is such that a slight decrease in the screen voltage will greatly increase the space charge and reduce the plate-current flow. Consequently, during the period in which no radio-frequency signal voltages are being received, the first audio-frequency tube is operating with such little plate current (near cutoff) that no amplification can occur in the output or plate circuit. Thus no disturbing voltages developed in the radio-frequency stages can be transferred into the power-amplifier tubes and the loud-speaker system between the resonant adjustments of the tuning circuits.

However, as soon as the LC circuit and the preceding radio-frequency stages are tuned to resonance with a desired signal frequency, a voltage will be developed across the LC circuit of the diode detector, and pulsating (rectified) audio-frequency currents will be applied as low-frequency voltage variations, across the GK terminals of the 78 $QAVC$ tube. These low-frequency audio variations, owing to the diode rectifying action, are applied as groups of negative pulses to the grid of the $QAVC$ tube through the coupling and leak resistance R_2 . These pulses are of a negative character by virtue of the signal current through R_L , as shown. In other words, the grid of the $QAVC$ tube will be negative with respect to the cathode K , which is at a positive potential with respect to the grid. The negative potential, applied as it is to the grid of the $QAVC$ tube, will reduce the plate-current flow in this tube, thereby reducing the voltage drop across the resistance R_1 . Hence the voltage increase on the screen of the first audio-frequency tube will restore the plate-current flow in its plate circuit and through L_2 . Thus the audio-frequency variations in the plate circuit in this tube will be transferred to the power amplifier and the loud-speaker system.

Hence, it may readily be seen that the 77 tube serves as a blocking device and will function only when radio-frequency voltages are built up across the LC circuit of the detector tube. Thus, since these voltages can only be established by a careful adjustment to resonance, all other disturbances between resonant adjustments will be rejected.

The $QAVC$ tube may be adjusted by the suppression-control potentiometer R_3 , so that the noise-suppression system will function for any signal level. In other words, if the screen voltage on the $QAVC$ tube is lowered by moving the sliding arm of the potentiometer down toward ground, the plate-current flow in the 77 tube will be increased, and, conversely, if the arm is moved upward, the screen voltage will increase and the cutoff point will be raised.

II. THEORY AND APPLICATION OF TUNED CIRCUITS

5.18. General Circuit Considerations.—The receiving circuit is fundamentally a generating device for the purpose of developing an e.m.f. of either radio or audio frequency at the grid of a vacuum tube. In addition, the circuit in itself may serve to increase the voltages at the grid of the tube through the medium of step-up transformers and properly designed L to C ratios. The circuit also may serve properly to segregate frequencies from one another (tune) by the variation of the circuit constants L , C and the mutual coupling between the circuits.

Theory of coupled circuits and tuning are the fundamentals of both the receiving and the transmitting circuits. It is essential that a knowledge of the alternating-current engineering principles covered in Chap. 2 be clearly understood, since these principles are directly applicable to all forms of receiving and transmitting circuits in which the problems of inductance, capacity, and resistance are involved.

The most common form of receiving circuit and its electrical equivalent is that illustrated in Fig. 5-26(a) and (b). Here the antenna and ground are shown connected to the primary winding of a radio-frequency transformer L_1 inductively coupled to a secondary winding L_2 which is tuned by a condenser C_1 .

The electrical equivalent [Fig. 5-26(b)] shows the component parts of the antenna-and-ground system which include the antenna inductance L_a , the antenna-to-ground capacity relationship C_a , and the entire antenna-circuit resistance R_a .

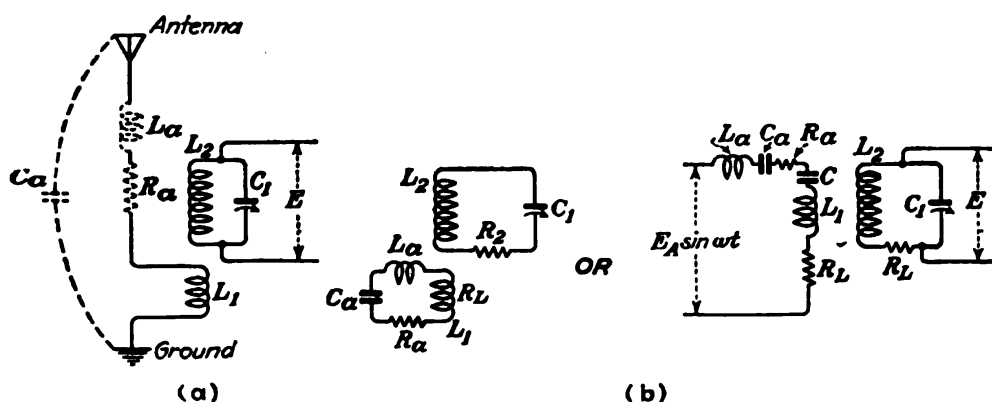


FIG. 5-26.—Simple receiving circuit and its electrical equivalent.

The antenna circuit, therefore, forms an oscillatory system which has resonant characteristics at a certain frequency in accordance with the ratio $f = \frac{1}{2\pi\sqrt{LC}}$. If

the value of L , C is such that the resonant frequency is, for example, at 500 kilocycles, and the resistance R_a is negligible, the circuit would be effectively responsive only to the one frequency to which it is tuned, and consequently it would induce a *maximum* e.m.f. across the secondary circuit L_2C_1 at that one frequency only, provided, of course, that the secondary circuit is also tuned to the same frequency.

In other words, the circuit L_1 would have a *maximum* current flowing in it only if the incoming-signal frequency is the same as that of the resonant period of the primary circuit. This would be a highly desirable condition if only one frequency were to be received, but, since in most radio receivers the circuit must respond to a band of frequencies, the antenna circuit must be broadly responsive so that a number of radio frequencies are present in the

form of a magnetic field around the primary winding L_1 . However, owing to the inherent direct-current and high-frequency resistance R_a in the antenna system, the sharply defined resonant characteristic is lost and the antenna circuit will respond to a broader band of frequencies such as is illustrated in Fig. 5-27. It will be noted that the resistance R_a is not included in the frequency equation, since

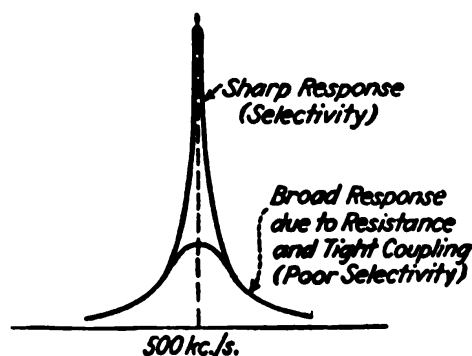


FIG. 5-27.—Sharp and broad tuning characteristics.

resistance does not affect the frequency but merely tends to broaden the response and reduce the amplitude.

The broadening effect due to resistance in a resonant circuit is known as the *circuit damping* and is an appropriate expression for the energy dissipation in any circuit; that is to say, the more resistance introduced, the greater is the circuit loss, or damping. This broadening effect is particularly useful in the reception of modulated signals where the amplitude of the radio-frequency wave is varied at an audible rate, such as in broadcast and certain types of marine transmitters.

Circuit damping has both desirable and undesirable effects. In a broadcast transmitter, the frequency due to the modulation process produces a band of frequencies on either side of the tuned frequency, called *side bands* (Sec. 4.15). These bands extend to approximately 7,500 cycles on either side of the tuned frequency, or a band width of 15,000 cycles. Now since this band width includes the musical-frequency spectrum, it is essential that the circuit to receive these frequencies respond to at least a 15,000-cycle band if fidelity in musical reproduction is to be obtained. Consequently, a sharply tuned circuit would produce a selective response, as indicated in Fig. 5-27, which would result in the entire loss of the band frequencies or side bands. Serious distortion would obviously result.

However, when using unmodulated or continuous-wave transmitters, the introduction of circuit resistance would merely reduce the amplitude of the signal voltage and reduce the overall sensitivity of the receiver. Hence, a sharply responsive or selectively tuned circuit is highly desirable for signals in which no side bands are involved and when a maximum amplitude is desired.

From this it may be seen that an antenna system which is to be sharply tuned must have a minimum of resistance, but, since this is practically impossible owing to the inherent coil and ground resistance, the alternative is to tune the antenna circuit for each frequency to be received. This can be accomplished by inserting a variable inductive or a capacitive reactance into the antenna circuit. If it is desired to tune to frequencies lower than the antenna natural-resonance period, an inductance coil is inserted, and, if it is desired to tune to frequencies higher than the antenna natural-resonance period, a variable condenser is inserted.

5.19. Simple Analysis of the Tuned Circuit.—It can readily be seen from Fig. 5-26(a) that the antenna circuit is equivalent to a series-resonant circuit, while the secondary circuit is of the parallel-resonant type. Consequently the impedance Z offered to the currents in both types of circuits will be quite different. This is an important factor since the voltages developed across any series or parallel combination will be dependent upon the impedance of the respective circuits.

In the primary portion of a receiving circuit, therefore, it is essential that a maximum current shall flow through the primary coil L_1 in order to develop a maximum field for the transfer of energy into the secondary circuit L_2C_1 . This condition is realized when the capacitive reactance X_c is equal to the inductive reactance X_L at some particular frequency.

The impedance of the circuit under these adjustments will be $Z = R$, since series resonance is expressed

$$|Z_0| = R^2 + \sqrt{(X_L - X_C)^2} \quad (11)$$

or,

$$Z = j\omega L + R + \frac{1}{j\omega C}$$

Hence, since at resonance the impedance $Z = R$, the current flow in the circuit due to $E_A \sin \omega t$ will be entirely dependent upon the circuit resistance. If, therefore, this resistance is maintained as low as possible, a maximum current in the primary L_1 may

be developed. The resistance R is primarily the high-frequency resistance in the coil, the antenna and earth losses, and the direct-current resistance due to the wire, which is dependent upon the number of turns and the size of the wire used.

The transfer of energy into the circuit L_2, C_1 may, under these conditions, be considered maximum and, if the circuit L_2, C_1 is tuned to resonance, a maximum voltage E will develop across the parallel mesh. Since it has been shown that the vacuum tube is primarily a voltage-amplifying device, this voltage must be made as large as possible so that the gain $\mu \times E$, through the tube will be maximum.

Hence the impedance of the parallel-resonant circuit should be infinite if a maximum e.m.f. is to be developed across it. Therefore, for parallel resonance

$$Z_o = \frac{X_c \sqrt{R_L^2 + X_L^2}}{\sqrt{R_L^2 + (X_L - X_C)^2}} \quad (12)$$

If the resistance of the coil is small compared to the reactance, as is usually true, the equation may be simplified to

$$Z = \frac{\omega^2 L^2}{R} \quad [\text{Chap. 4, Eq. (5)}]$$

Thus a parallel-resonant circuit will approach an infinite impedance if the resistance R_2 is maintained as close to zero as possible. In other words, an increase of the coil resistance will decrease the impedance of the parallel combination.

Several other factors, however, will also affect the impedance relations between coupled circuits. The most important of these is the reactionary magnetic effects between the primary and secondary windings due to the mutual coupling between the circuits.

For example, if the two coils L_1, L_2 are very tightly coupled, the energy developed in the secondary circuit will be partly dissipated in transferring some of its energy back into the primary circuit owing to the mutual coupling. This is equivalent to increasing effectively the resistance R_2 of the secondary circuit L_2, C_1 , so that the circuit impedance may be considerably reduced. In addition, the reflection of energy back into the primary circuit (called *reflected resistance*) will tend to raise the resistance of the primary circuit, so that the current flow in the series-resonant circuit will be reduced. The introduction of this resistance will increase the damping of the antenna circuit, which will tend to make it more broadly responsive, or less selective. Thus, since the resistances of both the primary and secondary circuits have been increased, the voltage E will be reduced. Therefore the broadening effect produced by the coupling reactions will make the circuit less selective, and interference from adjacent frequencies will result. One advantage, however, which will be derived from this condition is that the reception of modulated waves from broadcast transmitters will be more readily accommodated, or, in other words, the side-band frequencies will not be cut off and better fidelity will result.

Hence, the greater the mutual coupling (M) between two coils L_1 and L_2 , the greater will be the reactionary effects and the broader the tuning response.

$$M = \sqrt{L_1 L_2} \times k \quad [\text{Chap. 2, Eq. (11)}]$$

If the coupling between two coils is such that all of the lines of force produced by the primary and the secondary coils interlink, the percentage of coupling will be 100 per cent. But since this is practically impossible because of some flux leakage, the total coupling must be at some point below 100 per cent. This percentage may be calculated by taking the ratio of the mutual inductance (M) to the maximum theoreti-

cal value of L . This is called the *degree* or *coefficient of coupling* (k) and is expressed by the ratio

$$k = \frac{M}{\sqrt{L_1 L_2}} \quad [\text{Chap. 2, Eq. (20)}]$$

From this, it may be readily seen that the mutual inductance between two coils will be maximum when the coils are tightly coupled and minimum when they are loosely coupled.

The modulated radio-frequency voltages E that are developed across any parallel mesh may then be applied to a suitable amplifying or rectifying device for either increasing the amplitude of these voltages or changing them into low-frequency asymmetrical pulsations (detection).

5.20. Filter Circuits.—In contrast to resonant circuits which are designed for operation at a definite resonant frequency, there is the filter circuit which provides attenuation or transmission over a definite slice of the frequency spectrum. Filters are used in radio-, audio-, and

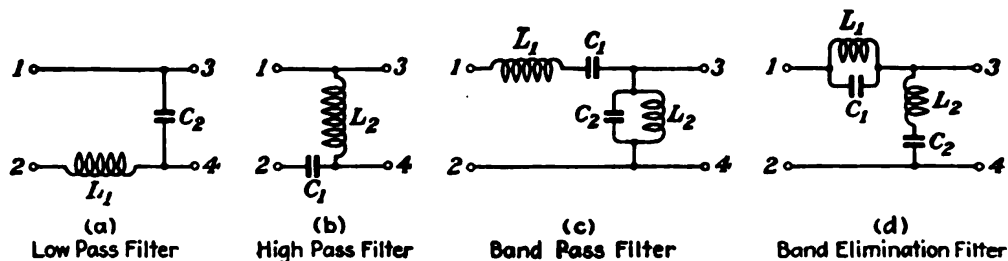


FIG. 5-28.—Filter circuits.

commercial-frequency circuits. When used in radio or audio circuits these circuits are referred to simply as *filters*, but, when used on commercial frequencies on power-supply apparatus, they are referred to as *ripple filters*. Ripple filters will be treated in detail in Chap. 6 on Electronic Power Supplies.

For design purposes, filters are divided into four classes, namely, low pass, high pass, band pass, and band elimination. These various types are shown in Fig. 5-28. The circuits shown are known as the *constant K type* because the effective impedance (or the geometric mean) of both the series and shunt sections remains constant over all the frequencies at which the filter operates, and this resistance is equal to the terminating resistance. The various classes of filters will now be discussed separately.

a. Low-pass Filters.—This form of filter is a circuit which is designed to attenuate all frequencies above a definite cutoff point (f_c) and to pass all frequencies below this point.

The low-pass filter may take the form of a simple- or complex-series or parallel-resonant circuit, or both. A simple L -type low-pass filter is shown as circuit (a). This circuit is derived as follows:

$$L_1 = \frac{R}{\pi f_c} \quad (13)$$

$$C_2 = \frac{1}{\pi f_c R} \quad (14)$$

where R is the resistance of the terminating impedance connected across 3 and 4. L and C are in henrys and farads, respectively. The cutoff frequency in cycles, f_c , is found by the equation

$$f_c = \frac{1}{\pi \sqrt{LC}} \quad (15)$$

b. High-pass Filters.—A circuit which is designed to pass all frequencies above a definite cutoff point and attenuate to a minimum value all frequencies below this point is called a *high-pass filter*. This circuit (b) may be derived as follows, using the same symbols as before:

$$L_2 = \frac{R}{4\pi f_c} \quad (16)$$

$$C_1 = \frac{1}{4\pi f_c R} \quad (17)$$

$$f_c = \frac{1}{4\pi \sqrt{LC}} \quad (18)$$

c. Band-pass Filters.—A circuit designed to pass a band of frequencies extending over a definite portion of the frequency spectrum and to attenuate all other frequencies is called a *band-pass filter*. A schematic diagram of such a circuit is shown at (c) and is derived as below. Let f_1 = lower cutoff frequency and f_2 = upper cutoff frequency. Then

$$L_1 = \frac{R}{\pi(f_2 - f_1)} \quad (19)$$

$$L_2 = \frac{(f_2 - f_1)R}{4\pi f_2 f_1} \quad (20)$$

$$C_1 = \frac{(f_2 - f_1)}{4\pi f_2 f_1 R} \quad (21)$$

$$C_2 = \frac{1}{\pi(f_2 - f_1)R} \quad (22)$$

$$f_1 = \frac{\sqrt{(L_2 + L_1)C_1} - \sqrt{L_2 C_1}}{2\pi L_1 C_1} \quad (23)$$

$$f_2 = \frac{\sqrt{(L_2 + L_1)C_1} + \sqrt{L_2 C_1}}{2\pi L_1 C_1} \quad (24)$$

d. Band-elimination Filters.—This type of circuit which is shown as (d) operates conversely to the band-pass filter in that it attenuates rather

than passes a slice of the frequency spectrum. This circuit may be derived as follows, using the same symbols as before:

$$L_1 = \frac{(f_2 - f_1)R}{\pi f_1 f_2} \quad (25)$$

$$L_2 = \frac{R}{4\pi(f_2 - f_1)} \quad (26)$$

$$C_1 = \frac{1}{4\pi(f_2 - f_1)R} \quad (27)$$

$$C_2 = \frac{f_2 - f_1}{\pi R f_1 f_2} \quad (28)$$

5.21. Isolation and Band-pass Circuits.—Although the important con-

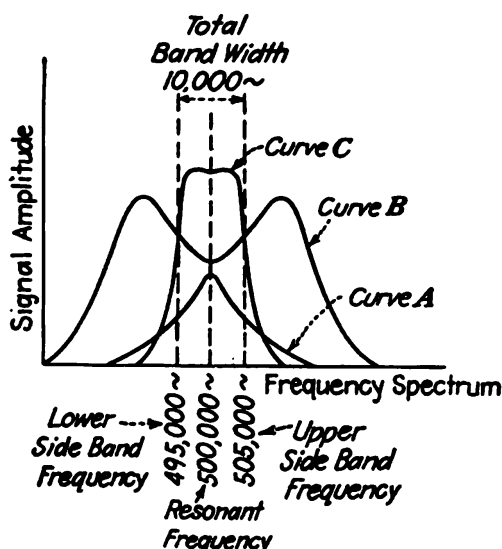


FIG. 5-29. Curves illustrating band-pass effects.

sideration in all tuned-circuit designs is to develop a maximum voltage to the vacuum-tube amplifier or detector circuits, it has been shown that selectivity and broadness are also desirable. In the reception of broadcast signals both selectivity and broad signal response are required in order that interference may be eliminated and fidelity obtained. To accomplish this a number of tuned circuits must be employed to secure a preferred result.

The band-pass characteristic may be obtained in various ways by varying the coefficient of coupling

or the ratio of X_L/R , called circuit Q , of each of the coupled circuits by:

1. Overcoupling L_1 and L_2 , tuned to the same frequency.
2. Decreasing the circuit Q of L_1 and L_2 with shunt resistance.
3. Detuning the secondary, with or without changing coupling.
4. Combining a simple resonant circuit with a coupled combination.

Regardless of which method is used, a band-pass characteristic may be obtained, as illustrated by the secondary-current curves in Fig. 5-29. Curve A shows the effect when high Q circuits are loosely coupled and tuned to the same frequency. Curve B shows the effect on the coupled circuit produced by the first or third method.

For very broad pass bands where it is desirable to have uniform response over the band, the dip in the center caused by one of the first three methods of obtaining wide response can be eliminated by combining the effect of a simple resonant circuit with that of the coupled combina-

tion. By proper adjustment of the circuit a uniform pass band over a wide range can be obtained.

The desirable shape of a band-pass curve to pass a given slice, or band, of the frequency spectrum and to discriminate against all frequencies lying outside this band is shown as curve *C*. This type of characteristic can be obtained by applying discriminately any of the methods listed above until the desired shape is secured.

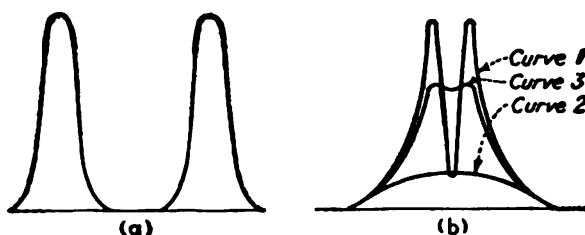


FIG. 5-30.—Curves illustrating individual and combined coupling reactions.

The curves in Fig. 5-30 show the effect on secondary current as the coupling between two resonant circuits, each tuned to a different frequency slightly each side of the mid-point of the band-pass range, is increased. Curve 1 shows the effect with loose coupling, where two resonance points are distinctly present, with a minimum current at the frequency-band mid-point. Curve 2 shows the effect with tight coupling, where the entire characteristic is merged into a low, broad, flatter response. Curve 3 shows the desired band-pass shape, wherein, by proper manipula-

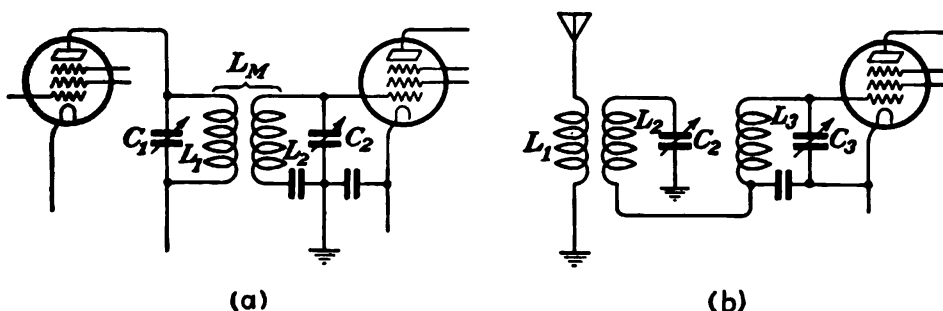


FIG. 5-31.—Band-pass filter circuits.

tion of the coefficient of coupling, or the *Q* of the primary and secondary circuits, an effective compromise between curves 1 and 2 is obtained.

Band-pass filter circuits may employ inductive coupling, direct magnetic coupling, or direct capacitive coupling. The effect of each is substantially similar.

Perhaps the simplest and most practical applications of the band-pass filter are those shown in Fig. 5-31. In diagram (a) we have the most commonly used form, consisting of two inductively coupled tuned circuits. The width of the pass band is controlled by varying the mutual coupling coefficient L_m . In diagram (b) we have a special application, wherein the tuned secondary circuit L_3C_3 is tuned to the desired frequency

and the inductive coupling to the primary L_1 controlled by the series-tuned circuit L_2C_2 .

Although the band-pass filter produces the desired result in accommodating side-band frequencies, it presents a disadvantage in that the currents circulating in the various-tuned circuits produce a dissipation of the signal energy which ultimately reduces the signal voltages applied to the radio-frequency amplifier tubes. This disadvantage, however, may be overcome by introducing an additional stage of radio-frequency amplification.

5.22. Rejector or Trap Circuits.—It is frequently necessary in receiving or transmitting systems to introduce an additional tuned impedance which will offer to the desired frequency a high-reactance path, while to undesired frequencies it will provide a low-reactance path. In this

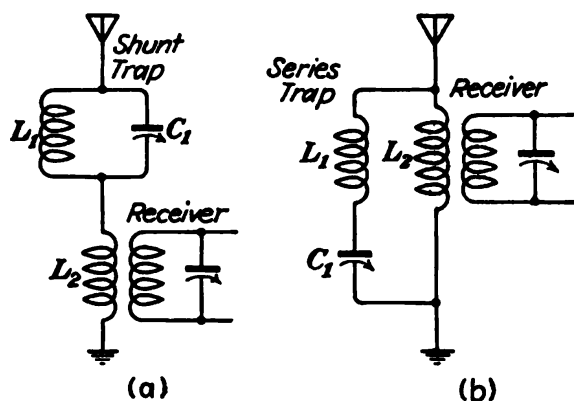


FIG. 5-32.—Rejector and acceptor circuits (wave traps).

manner it will be possible to have two tuned circuits functioning simultaneously so as to accept or reject certain frequencies, as desired.

Figure 5-32(a) illustrates a shunt rejector wave-trap circuit which may be designed to eliminate undesired frequencies by adjusting the parallel-resonant trap circuit L_1C_1 to that of the undesired frequency while the values of L_2 and C_2 are adjusted to the desired frequency.

It has previously been shown that the impedance of a parallel-resonant circuit, when adjusted to resonance, will be

$$Z_{p.r.} = \frac{L}{CR} \quad \text{or} \quad \left(\frac{X_L^2}{R} \right) \quad (29)$$

while that for a series-resonant circuit at resonance will be

$$Z_{s.r.} = \sqrt{R^2 + (X_L - X_C)^2} = R \quad [\text{Chap. 2, Eq. (43)}]$$

If, therefore, the trap circuit is critically adjusted so that the ratio L/CR of L_1C_1 offers a high impedance to the undesired signal frequency, a minimum current of that frequency will flow in the antenna circuit and a minimum voltage will be present across the receiver coil L_2 . At the same time the trap circuit L_1C_1 offers less than maximum impedance to the

desired signal frequency (the amount of impedance offered depending on how far the desired signal frequency is from the resonant frequency of L_1C_1) and a working voltage at the desired frequency is set up across the receiver coil L_2 .

The efficiency of the rejector circuit will depend greatly upon the accuracy of its adjustment and its impedance value. It is imperative that the coil L_1 possess a high Q characteristic, otherwise the degree of rejecting effect to the undesired frequency may be greatly reduced.

Figure 5-32(b) illustrates a series acceptor wave-trap circuit. This type of wave trap is connected in shunt with the input terminals of a radio receiver. To be effective the trap circuit L_1C_1 must be tuned to the undesired signal. Under these conditions the trap circuit offers a minimum impedance to the undesired signal frequency, according to the equation for series resonance given above, and the undesired signal frequency is by-passed to ground through the trap circuit. Under these conditions a minimum current at the undesired frequency will flow through the receiver coil L_2 , and a minimum signal at the undesired frequency is passed on to the radio receiver. At the same time the antenna circuit, being tuned to the desired frequency, offers a minimum impedance to the desired frequency; a maximum current at this frequency flows through the receiver coil L_2 and is passed on to the radio receiver.

5.23. Regenerative Receiver.—It will be remembered that the rectifying action of the tube, due to the grid condenser and leak, resulted in a low- and a high-frequency current flow in the output-plate circuit, in which the low-frequency pulse passed through the headphones (telephones) and the high-frequency pulse was by-passed through the fixed condenser, shunting the headphones.

In a regenerative system it is this radio-frequency current in the plate circuit of the detector which can be used for radio-frequency amplification of the received signals by a feedback of energy to the grid of this tube through either an inductive or capacitive coupling.

Figure 5-33 illustrates a typical regenerative circuit in which the coil L_2 is used to feed back the signal radio-frequency variations in the plate circuit to the grid to produce an increased signal variation and, consequently, a louder response in the headphones.

The explanation of this action is as follows:

In the high-frequency grid circuit L_2C_2 , where the damped-signal variations are fed to the grid after they have been induced by conditions of resonance from L_1C_1 , there is always a certain amount of ohmic resistance present, which results in a loss of some of the signal energy, and, consequently, an increase in the signal damping. This loss, due to the circuit resistance, is called the *positive resistance* of the circuit.

When the signal variations are applied to the grid of the regenerative receiver, there will be a resultant high-frequency plate-current component which will flow through the coil L_2 and the radio-frequency by-pass condenser. Now, if the coil L_1 is inductively related to L_2 , an e.m.f. will be induced across L_2C_2 which will be in phase

with the high-frequency e.m.f. set up in the same circuit by the incoming signal. If, then, the coil L_2 is wound so as to provide the proper feed-back coupling between the plate and the grid circuits, the positive ohmic resistance of the circuit will be partly neutralized, which will result in a decrease of damping and therefore a higher amplitude of the signal variations and, consequently, a louder signal response in the telephones. The feed-back energy from the plate to the grid circuit acts to neutralize the effect of the positive resistance and is called *negative resistance*.

It is important to note that the neutralizing effect increases as the feed-back coupling L_2 is made closer, and a point may be reached where the damping is so small, owing to the neutralization of the positive resistance by the negative resistance, that the circuit will start oscillating. An incoming modulated or damped signal will by virtue of its sharply tuned character have its side-band frequencies narrowed or cut off, if the circuit is oscillating, and the signal will be heavily distorted and possibly inaudible.

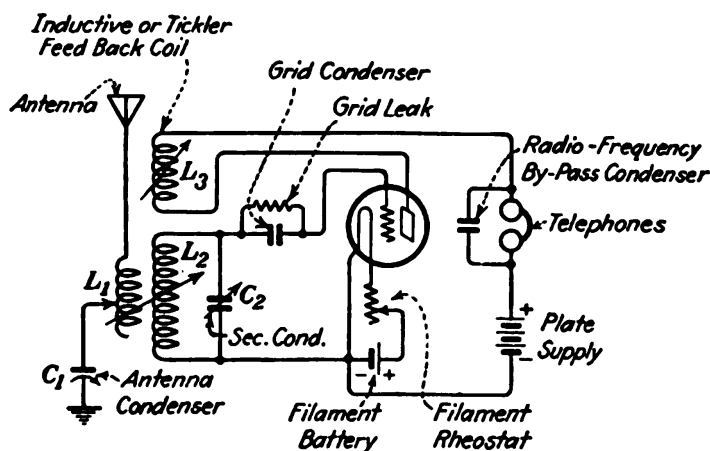


FIG. 5-33.—Regenerative receiver circuit.

It can thus be seen that a regenerative system will give increased amplification of damped and modulated signals only up to a certain point, that is, a little below the oscillating point.

If, on the other hand, however, incoming signals of an undamped character (*CW*) are applied to the grid of the regenerative detector, no signals will be heard until the tickler coil is adjusted to the point of self-oscillation. When the regenerative detector is brought to the point of self-oscillation, the sustained voltage variations on the grid due to oscillation are combined with the incoming-signal voltages, which produces a resultant "beat" in the plate circuit which is the difference between the two sustained frequencies. Hence, if the incoming-signal frequency is 500 kilocycles, and the tickler coil is so adjusted that the circuit will self-oscillate at 501 kilocycles, the resultant beat frequency will be 1,000 cycles. Consequently, since this beat frequency is in the audio-frequency range, low-frequency variations will pass through the telephone circuit which will render them audible. By the critical adjustment of the tickler coil, the self-oscillating frequency may be varied to change the resultant beat frequency to any desired audio-frequency tone.

This system whereby a single tube functions as an oscillator and a detector is the most commonly used for the reception of telegraphic continuous-wave signals and is generally known as the *autodyne* method of beat reception.

If a receiver with a non-regenerative detector is used no *C-W* signals can be received unless a separate or external oscillator is provided to beat against the incoming signal.

It is readily seen that a regenerative detector used as an autodyne, that is, in an oscillatory condition, will radiate energy through the antenna system if connected as in Fig. 5-33. Usually this radiation is of such a feeble character as to cause no serious interference. However, in order to prevent the autodyne from causing interference, it is the usual practice, in modern receivers utilizing this type of detector, to precede the detector with one or two stages of radio-frequency amplification. The radio-frequency tube (or tubes) then acts as a *buffer tube* and prevents energy generated in the autodyne tube from reaching the antenna where it would be radiated as an interference wave.

5.24. Superregenerative Receiver.—It has been shown in the regenerative circuit that the sensitivity of the receiver is dependent upon the introduction of sufficient feedback from the plate to the grid circuit to introduce an e.m.f. which will reduce the inherent circuit-resistance losses

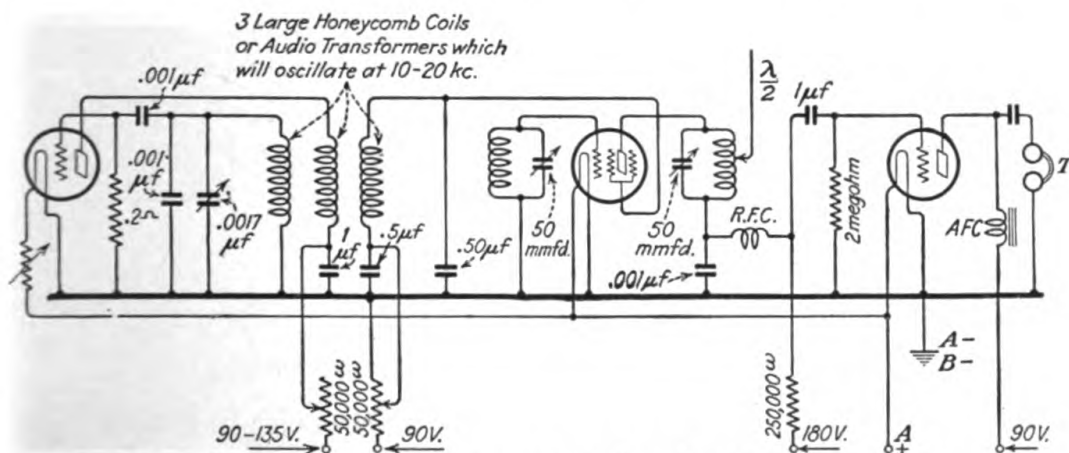


FIG. 5-34.—Superregenerative receiver circuit for ultra-high-frequency reception.

and thereby increase the amplitude of the voltage applied to the grid of the detector tube. These voltages are increased up to a critical point just before the tube goes into self-oscillation.

In the superregenerative receiver it is possible to increase these voltages to a larger amplitude before the tube goes into self-oscillation, thereby greatly increasing the amplification or sensitivity of the receiver.

These conditions are obtained by coupling a local oscillator to the normal regenerative circuit and adjusting the local oscillator to the point in which the damping of the regenerative circuit is periodically decreased. This local generating frequency must be of a relatively low value so that the signal will just reach its maximum amplitude before the "quenching" action takes place.

Figure 5-34 illustrates a circuit arrangement of a highly sensitive superregenerative receiver for the reception of ultra-high frequencies.

5.25. Superheterodyne Receiver. *a. General Considerations.*—It has been shown that the gain in a radio-frequency amplifier depends upon

several general factors, namely, the efficiency of the circuit design, the number of tubes used, the μ of the tubes, and the ratio of turns in the primary and secondary windings of the radio-frequency transformer.

The voltage developed across the primary winding of a radio-frequency transformer is found by the equation

$$E_p = \frac{\mu E_o Z_p}{R_p + Z_p} \quad \text{volts (formula 7, Chap. 3)}$$

The voltage developed across the secondary of a radio-frequency transformer is found to be

$$E_s = \frac{\mu E_o Z_p}{R_p + Z_p} \times \frac{L_s}{M} \quad \text{volts (originally formula 5, Chap. 3)} \quad (30)$$

From this it may be seen that the gain of a single radio-frequency stage could be greatly increased by using a radio-frequency transformer

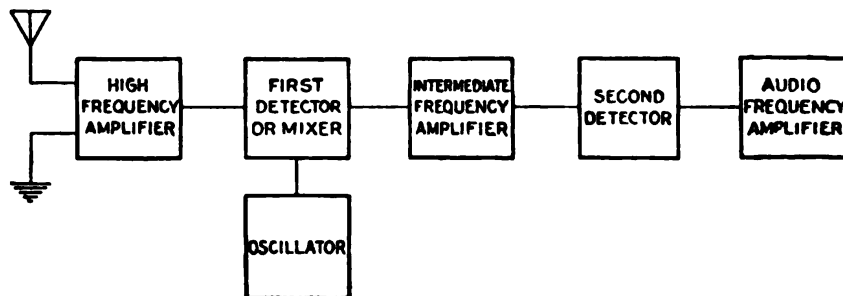


FIG. 5-35.—Block diagram of superheterodyne system.

with a very large turns ratio. This is, of course, quite impossible in a radio-frequency amplifier covering the broadcast band, since the large increase of L would reduce the frequency period of the circuit and make it possible to tune to low-frequency bands only.

If, however, a decreased frequency of say 175,000 cycles is passed through a radio-frequency transformer having a large turns ratio, a considerably greater voltage would be applied to the succeeding amplifier tube, resulting in a greater gain, E_2/E_1 . It is this principle which makes a single-stage superheterodyne intermediate-frequency amplifier a relatively higher voltage-amplifying device, and thereby greatly increases its sensitivity.

Figure 5-35 illustrates a block arrangement of the component units of a superheterodyne receiver as used for the reception of modulated or damped signals. The use of this circuit for the reception of undamped continuous waves (*CW*) (unmodulated) will be explained later.

The high-frequency unit may consist of a number of radio-frequency amplifier stages tuned to the particular frequency desired. These frequencies are then applied to a detector or mixer tube in which the signals are mixed with the local-oscillator frequencies and thus changed from a

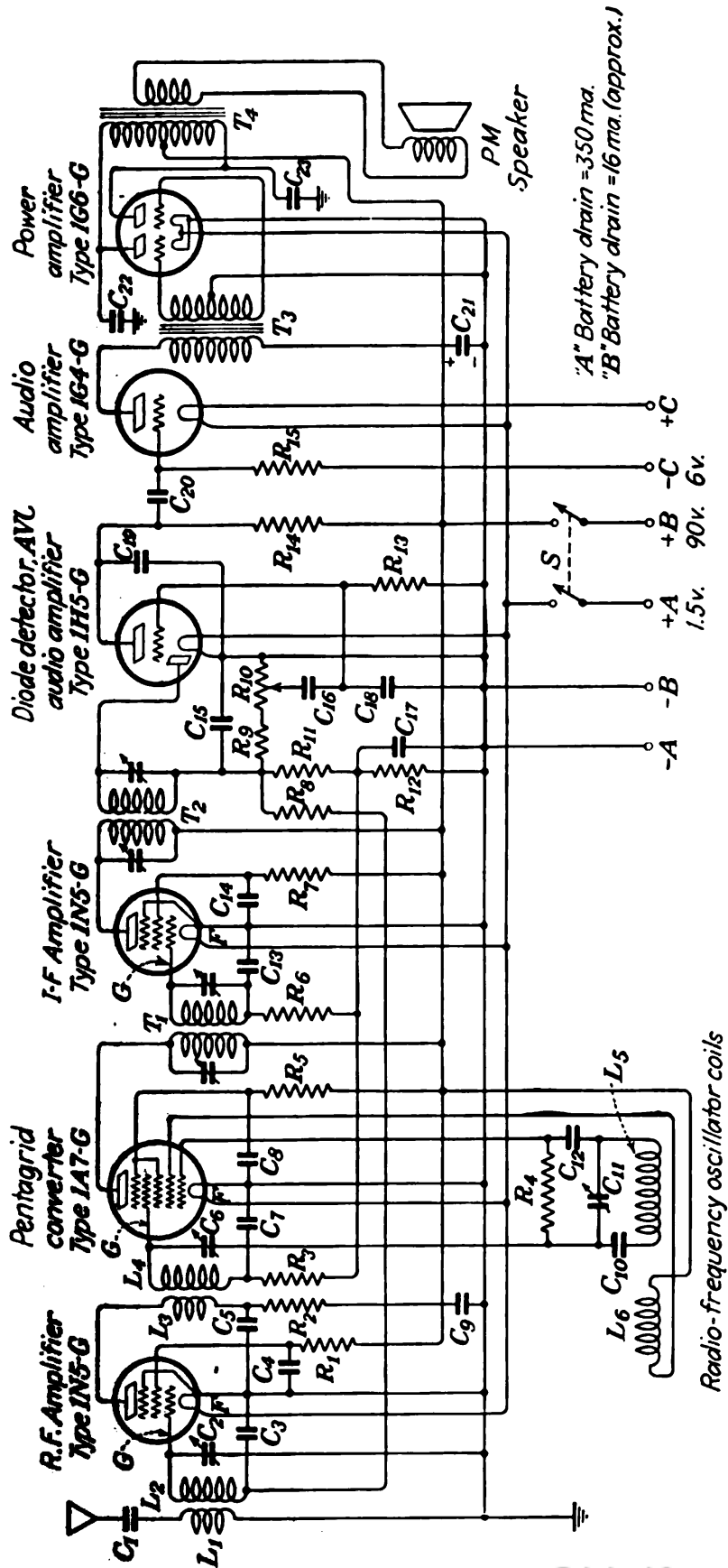


FIG. 5-36.—Superhetrodyne receiver circuit.

high to a lower frequency signal, so that they may be passed through a radio-frequency transformer of lower frequency characteristics. This type of transformer has an increased step-up ratio and, consequently, will develop larger voltages to be passed on to the succeeding tube, the intermediate radio-frequency amplifier.

The oscillator tube generates sustained oscillations which are also applied to the first detector tube. These oscillations are of such value that, when they are reacting with the incoming-signal voltage on the grid or plate of the first detector tube, they produce a wave which is the difference between the incoming signal and the oscillator frequency. If this difference, or beat frequency, lies somewhere in the lower frequency range, say 175 kilocycles, and the output transformer of the first detector tube is tuned to this frequency, the resultant signal will be applied to the grid of the succeeding tube. This latter tube is known as the intermediate-frequency amplifier. A number of these stages may be used depending upon the sensitivity desired.

From here the signal is applied to the second detector tube where it is rectified and amplified in the usual manner.

Figure 5-36 illustrates a complete superheterodyne receiver using high-gain tubes and efficient circuit characteristics. These principles apply to all types of superheterodyne receivers as may readily be seen by referring to some of the commercial types used in aircraft and marine communication.

b. Theoretical Operation of the Receiver for Modulated Waves.—Assuming that all voltages are applied, and that the tube filaments are lighted, the operation of the complete receiver is as follows.

When a signal voltage is developed across L_1 , an alternating current of a definite frequency will flow in the antenna circuit. This will produce a varying magnetic field around the winding and induce an e.m.f. across the secondary circuit L_2C_2 , if the circuit is adjusted to resonance. The voltage developed across the parallel mesh will then be applied between G and F of the radio-frequency amplifier through the by-pass condenser C_1 . The signal voltage E_s developed across G and F will be applied across the load impedance L_3 of an approximate value, μE_s . This results in a radio-frequency current variation in L_3 and C_3 . These variations are isolated from the supply circuit by the plate-filter resistance R_3 , thereby preventing magnetic interactions with other circuits common to the supply, thus increasing the efficiency and the stability of the amplifier.

The magnetic variations now present across L_3 are induced into L_4 . The increased signal voltage now present across G and F of the pentagrid converter tube develops a radio-frequency variation in the primary circuit of T_1 . However, since this circuit is resonant to a frequency of 175 kilocycles and the incoming frequency is in the broadcast spectrum of between 500 and 1,500 kilocycles, depending upon the adjustments of L_2C_2 , L_4C_4 , no e.m.f. will be developed across the secondary circuit of T_1 .

Let us assume the incoming radio signal to be at a frequency of 500 kilocycles. In order to transfer this signal through the 175-kilocycle intermediate-frequency (IF) transformer, the radio-frequency oscillator must be set into operation. The oscillator is of the inductive-feed-back variety and operates upon the fundamental principles of the vacuum-tube oscillator explained in the preceding chapter. Its function is performed by the pentagrid converter tube.

The condenser C_{11} is now adjusted so that the oscillator will generate a radio frequency which, when combined with the incoming-signal frequency of 500 kilocycles, will produce a beat frequency of 175 kilocycles.

With the radio-frequency oscillator assumed to be generating a frequency of 675 kilocycles, a voltage will be induced across the coil L_5 . Now, since there are already signal voltages developed across L_5 by the incoming signal, the combining of these two voltages in the circuit will generate an e.m.f. and a resultant beat frequency, which is the difference between the two, $675 - 500$, or 175 kilocycles. This condition is illustrated in Fig. 5-37. Actually both sum and difference frequencies exist in addition to the original ones, and the tuned plate circuit of the pentagrid converter selects the proper one.

This frequency is then induced into the 175-kilocycle resonant circuit, and an e.m.f. is developed across G and F of the intermediate-frequency amplifier tube. This frequency is amplified again through the second 175-kilocycle radio-frequency transformer T_2 , where it is applied across G and F of the second detector tube. This tube is biased near the cutoff point by the biasing resistor R_{13} , to produce the necessary rectifying action for detection of the 175-kilocycle modulated signal to effect audibility. The radio-frequency asymmetrical variations now present in the plate circuit develop group voltages across the by-pass condenser C_{19} , which are discharged as low-frequency or audio pulses through the plate-coupling resistance R_{14} . This resistance is used as the coupling medium instead of an audio-frequency transformer because of the high plate-resistance load required to match the high screen-grid tube impedance R_p .

The audio-frequency voltages now developed across R_{14} and the plate coupling condenser C_{20} are applied to G and F of the audio-frequency amplifier. The audio-frequency variations now present in the plate circuit of this tube are applied to the grid of the power tube through an audio-frequency transformer T_3 .

The bias voltages for the first four tubes are supplied, respectively, by the resistor groups R_4, R_{11}, R_{12} ; R_5, R_{12} ; R_6, R_{12} ; and by R_{13} . The required bias for the first audio tube is supplied by R_{15} and an applied $-C$ of 6 volts. No bias is required on the power-amplifier tube.

In addition to the high degree of amplification which may be obtained from the superheterodyne receiver, it possesses exceptional selective qualities owing to the good selectivity of the intermediate-frequency circuit.

One important difficulty encountered in the superheterodyne receiver is the interference caused in the radio-frequency stages owing to the reaction of the oscillator with certain other incoming-signal frequencies.

For example, let us assume that a signal frequency of 2,000 kilocycles is to be received. The oscillator may be adjusted to either 2,175 or 1,825 kilocycles, since the resultant beat in either case will be 175 kilocycles. Now, if a signal frequency of 2,350 kilocycles is also being received, the difference between 2,350 and 2,175 kilocycles is also 175 kilocycles. This is known as the *image frequency*. This interference may be eliminated by loosening the coupling in the radio-frequency transformers L_1, L_2 and L_3, L_4 (Fig. 5-36) thus making the circuit more selective.

Another method of suppressing the image frequencies would be to connect a parallel-resonant circuit in series with the grid of the first detector tube, and adjust the circuit so that it introduces infinite impedance to the image frequency. This may be accomplished by adjusting this circuit so that it will differ from the desired signal by twice the intermediate frequency, under which conditions no image frequencies will be introduced beyond the mixer circuit.

c. The Superheterodyne for Continuous-wave (C-W) Reception.—If it is desired to receive continuous waves with the superheterodyne receiver,

the second detector must employ the autodyne circuit, or an external oscillator must be coupled to the grid of this detector tube. The latter method is usually employed, and the external oscillator so used is referred to variously as the second oscillator or as the intermediate-frequency (*IF*) oscillator. Regardless of the system used, the circuits between the oscillator and the intermediate-frequency amplifier should be carefully shielded to avoid circuit instability.

Theoretical Operation: Let it be assumed that the *IF* circuit of the receiver is tuned to 175 kilocycles. An incoming *C-W* signal applied to the grid *G* of the pentagrid converter tube, as shown in Fig. 5-36, will pass through the intermediate stage owing to the heterodyning effect of the radio-frequency oscillator tube in accordance with the super-heterodyne principle explained in *b*.

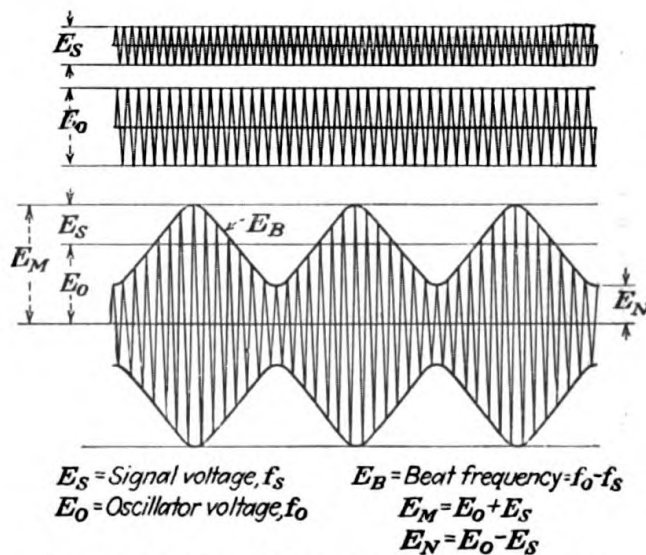


FIG. 5-37.—Circuit reactions in a beat receiver.

This signal eventually reaches the second detector tube, but it is still a continuous wave of an inaudible frequency (175 kilocycles). In order to make the signal audible, an *IF* oscillator, previously referred to, is coupled to the second detector and adjusted to beat against the 175-kilocycle *IF* signal. This produces an audible beat note equal in frequency to the difference between the *IF* signal and the *IF* oscillator frequency. Thus to get a 1,000-cycle note, the *IF* oscillator is adjusted 1,000 cycles either side of the 175-kilocycle *IF* signal; that is, to 174 or 176 kilocycles.

5.26. The Single-signal Receiver.—Although the superheterodyne receiver provides excellent selectivity on the broadcast band, it has been found greatly lacking in this respect on the very high frequencies in continuous-wave reception, owing to the crowding of stations into very narrow bands. This is particularly true in the short-wave amateur bands, and in the various marine bands in which *C-W* code transmission is used.

The inherent qualities of a quartz plate, which cause it to provide extremely selective tuning because of its sharp resonant characteristics

at certain frequencies, when operated at a fixed temperature, make it highly desirable for use as a filtering system in a receiving circuit to provide extreme selectivity, particularly in crowded high-frequency spectrums where rigid discrimination between stations is essential.

The characteristics of a receiver using a *crystal filter* are such that when the circuit is adjusted to approximately 1,000 cycles off the resonant point, the voltage gain of an interfering signal may be reduced as much as 97 per cent as shown in Fig. 5-38. Comparing this with the results obtained with a superheterodyne receiver without a crystal filter shows that in the latter the interfering signal, 1,000 cycles off resonance, is

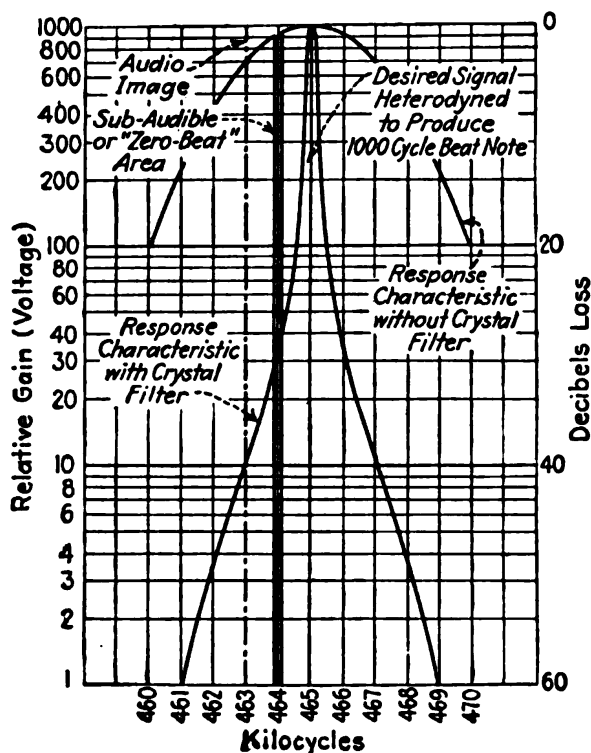


FIG. 5-38.—Response curves with and without a quartz-plate filter. (Courtesy of Hammarlund Manufacturing Company.)

reduced only 5 per cent. This indicates that the crystal filter is highly desirable for the reception of the unmodulated or *C-W* signal, such as is used in code transmission, but that it is obviously undesirable for broadcast frequencies where the frequency band must be 10 kilocycles wide to accommodate the side bands in the musical spectrum.

It has been previously shown that the greatest difficulty encountered in the superheterodyne receiver, however, is the interference due to the so-called *image frequency*. This image frequency will be particularly objectionable on crowded *C-W* bands, owing to the close proximity of stations. With the crystal filter, however, it is seen on the chart that the interfering image-frequency signal may be reduced to a negligible quantity (99 per cent) before it reaches the *IF* amplifier circuit.

Theoretical Operation: It has already been shown how the *IF* oscillator in the superheterodyne receiver serves to make *C-W* reception audible. However, other factors enter into the problem when the receiver is used on crowded frequency channels, resulting sometimes in serious interference. Such a situation will now be explained.

Suppose station *A* transmitting on a frequency of 6,000 kilocycles is being received. This means that the radio-frequency oscillator of the receiver must be adjusted to produce an intermediate beat frequency of 175 kilocycles, assuming this frequency, as usual, is the *IF* of the receiver. Thus the radio-frequency oscillator must be adjusted to 5,825 or 6,175 kilocycles.

Now suppose station *B*, capable of radiating an interfering signal, is transmitting on a frequency of 5,998 kilocycles which is 2 kilocycles lower than the desired signal. Thus when the emissions of *A* and *B* interact, a heterodyne frequency of 2 kilocycles is generated.

There are then present, in addition to the intermediate frequency of 175 kilocycles, two other frequencies, (1) the 2 kilocycles and (2) the radio-frequency oscillator frequency which can be assumed to be 6,175 kilocycles. These frequencies heterodyne,

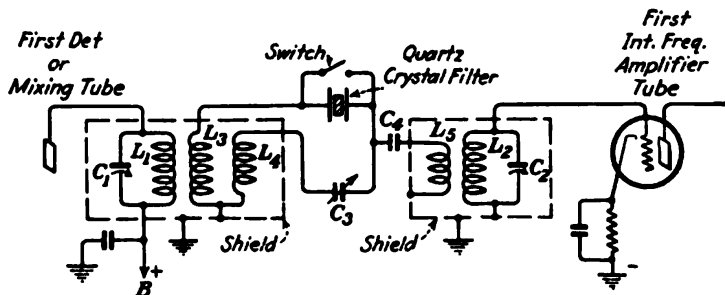


FIG. 5-39.—Quartz-plate filter circuit.

with the result that frequencies to the value of 6,173 and 6,177 kilocycles are generated, resulting in two new intermediate frequencies of 173 and 177 kilocycles. These are very close to the resonant frequency of the *IF* amplifier, and consequently a considerable amount of energy gets through the *IF* stage. These interfering frequencies are capable of producing the same effect on the second detector as the desired signal; they are the *image*, so to speak, of the desired signal, and they are, therefore, called *audio-image frequencies*. The reason for the prefix *audio* is that they produce an audio response, by heterodyning or beating with *IF* oscillator, similar to that of the desired signal.

Obviously, if these interfering frequencies could be prevented from reaching the *IF* amplifier in the first place, they could not finally reach the second detector and result in audio-image frequencies. It is to this function that the crystal filter, as used with the superheterodyne single-signal receiver, lends itself. The method of introducing the filter into the superheterodyne circuit is shown in Fig. 5-39.

The connection diagram is conventional, except for the provision made for the introduction of the crystal filter. The primary L_1 and the secondary L_2 of the coupling transformer are placed in separate shielded compartments. The split windings L_3, L_4 are inductively coupled to L_1 , thereby providing for an input circuit to the crystal filter. The output of the crystal is inductively coupled to the secondary L_2 through C_4 and L_6 . At resonance, L_1 and L_3 , and L_5 and L_2 are matched impedances.

The coil L_4 and the condenser C_3 neutralize the capacity of the crystal holder plates. Coils L_3 and L_4 have induced in them e.m.f.s. which are 180 degrees out of phase. Therefore, when C_3 equals the capacity of the crystal-holder plates, any currents which these plates might by-pass through their capacity are canceled out by

currents in opposite phase fed through C_1 . This leaves only the signal c.m.f.s. passed by the crystal free to reach the input circuit of the *IF* amplifier.

The setting of C_1 , therefore, governs the selectivity of the crystal, and the band passed through the crystal filter can be slightly widened, enough to make speech intelligible, but not enough for broadcasting which requires a much wider band. This condenser for this reason is sometimes known as the *interference control*.

This system is of great value in making the handling of traffic possible in what would otherwise be an overcrowded spectrum. It promises soon to be almost indispensable on receivers used in certain frequency bands.

5.27. General Communications Receiver.—THE NATIONAL COMPANY'S HRO RECEIVER.—Although this receiver is perhaps most widely known as an amateur communications receiver, its excellent design and working characteristics make it very suitable for study as a working model of a modern superheterodyne, incorporating the fundamental principles thus far studied in this chapter. It can be looked upon as a typical general communications receiver.

a. General Description.—The HRO receiver is a high-frequency superheterodyne employing nine tubes, as follows:

First R.F.	58	or 6D6
Second R.F.	58	or 6D6
First detector.	57	or 6C6
High-frequency oscillator.	57	or 6C6
First I.F.	58	or 6D6
Second I.F.	58	or 6D6
Diode detector, AVC, first audio.	2B7	or 6B7
Second audio.	2A5	or 42
Beat-frequency oscillator.	57	or 6C6

Unless otherwise specified, all models are equipped with 6.3-volt tubes, for either alternating-current or battery operation. The $2\frac{1}{2}$ -volt tubes can be used if desired, since the two types are interchangeable, but the 6.3-volt tubes are to be preferred.

For alternating-current operation, the receiver is adjusted to give best performance with the National type 697 AB power unit, which delivers 230 volts at 75 ma. and 6.3 volts at 3.1 amp. A schematic circuit diagram is shown in Fig. 5-40.

The battery model, type HRO-B, is adjusted for maximum performance with a plate potential of 180 volts at a current drain of approximately 55 ma. Normal operation from alternating-current lines with the HRO-B can be secured by the employment of a National type No. 5886 power pack, a unit which, under load, delivers approximately 170 volts direct current at 50 ma. and 6.3 volts alternating current at 3.1 amp.

All voltage dividers and bias requirements are built into the receiver.

Other power units may be used, provided that they will fulfill these specifications closely, but it is important that an adequate heater supply be furnished to compensate for the voltage drop in the heater leads of the power-supply cable.

b. Antenna.—The input circuit of the HRO is arranged for operation with either the doublet type or the single-wire type of antenna. There are two input binding posts, marked ANT and GND. When using a single-wire antenna, the leadin should be connected to the antenna post, and the short flexible lead, which is connected to the chassis near the ground post, should be clamped under the GND terminal. An external

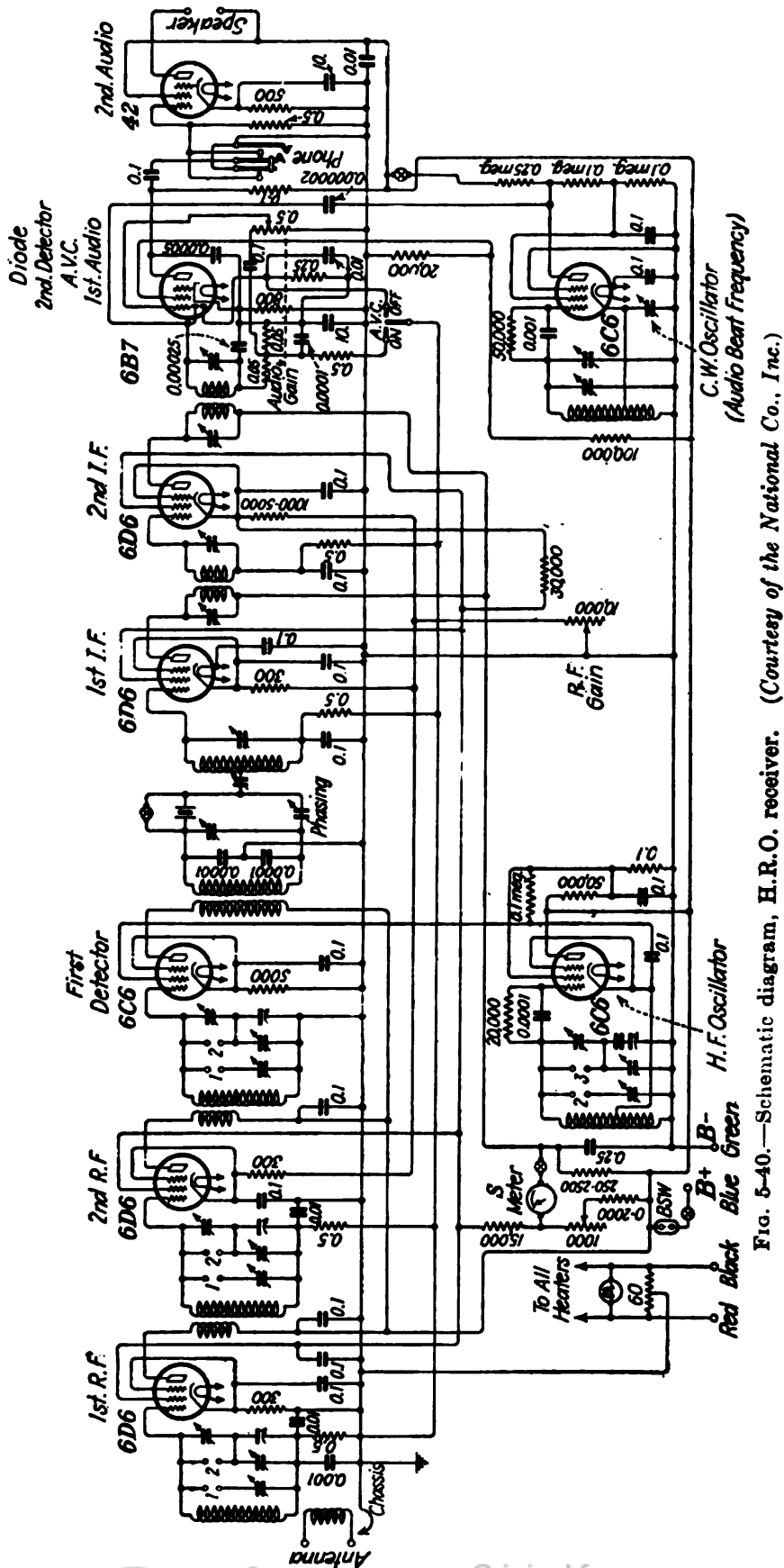


Fig. 5-40.—Schematic diagram, H.R.O. receiver. (Courtesy of the National Co., Inc.)

ground connection may or may not be necessary, depending upon the installation. The ground is usually desirable when receiving wave lengths above 100 meters, but for wave lengths below 50 meters, the use of a ground may actually weaken signals. Doublet antenna feeders should be connected directly to the input terminals, and the flexible ground connection, mentioned above, is not used at all.

The input impedance of the receiver varies over the total frequency range but averages about 500 ohms.

c. Output Circuit.—The plate circuit of the output tube is brought to the output tip jacks located at the rear left-hand side. There is no output transformer in the receiver.

The speaker requirements are not at all critical, but tone quality will, of course, depend almost entirely upon speaker characteristics. A good magnetic speaker will be satisfactory, provided it is capable of carrying the plate current of the output tube (about 30 ma.). Many magnetic speakers will require a filter system, however, and

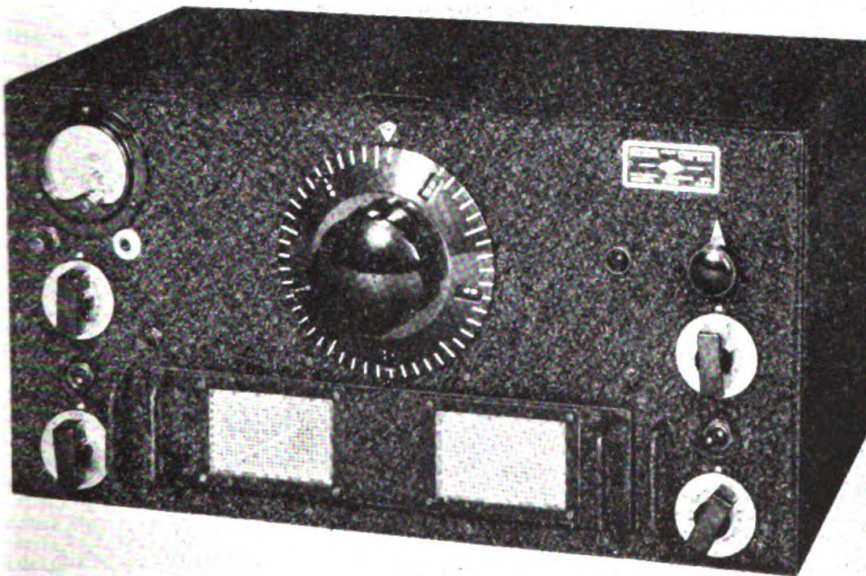


FIG. 5-41.—Front view, H.R.O. receiver. (Courtesy of the National Co., Inc.)

such a filter may consist of a 1-to-1 transformer, or a 30-henry choke and a 1-mf. condenser.

Dynamic speakers are, in general, superior to the magnetic types, but if these are used some provision must be made for field excitation, since this power cannot be obtained either from the receiver or the power unit. For this reason, the permanent magnet type of dynamic speaker is recommended, no field excitation being required. The output impedance of the HRO is 7,000 ohms, and a dynamic speaker must, of course, have a suitable built-in coupling transformer of 7,000-ohm input impedance.

A headphone jack is located on the front panel, just below and to the right of the signal-strength or S meter. This jack is wired into the output of the pentode section of the 6B7. When the phones are plugged in, the signal input to the last tube is completely disconnected. It is important, however, that the plate circuit of the output tube be completed at all times. If the speaker is to be disconnected, a jumper must be inserted in the tip jacks to connect them together. If this precaution is neglected, the output tube may be seriously injured.

d. Controls.—The main tuning dial is located near the center of the front panel and operates the four-gang tuning condenser.

Starting at the top right-hand side of the front panel (see photo, Fig. 5-41) the uppermost knob is the variable selectivity control of the single-signal crystal filter. With the crystal filter in use, minimum selectivity will be found with the pointer nearly vertical. Rotating the knob in either direction from this point will increase the selectivity. When the filter is not in use, the knob should be set at the point giving maximum volume and sensitivity.

Immediately below the selectivity control is the phasing control and the crystal filter switch. When this control is rotated to 0, the crystal filter is disconnected. When the control is at any other setting between 1 and 10, it acts as a phasing condenser for balancing the crystal bridge circuit and eliminating heterodynes.

The switch below the phasing control is connected in the *B+* lead of the receiver, and its purpose is to shut off the receiver during periods of transmission or when changing coils. This last function is important. Series connected with the *B+* switch and mounted at the rear of the chassis is a pair of contacts *BSW* intended for use with relay control of the receiver.

The bottom control on the right-hand side is a radio-frequency gain control, connected to the second radio-frequency tube and to the two intermediate-frequency tubes.

At the bottom left-hand side of the front panel is located the *CW* oscillator switch and vernier tuning control. The *CW* oscillator is used to obtain an audible beat note when receiving *CW* signals or to locate the carrier of weak phone and broadcast stations. After the phone carrier has been found, the *CW* oscillator is, of course, turned off.

The switch just above the *CW* beat oscillator dial is for turning the *AVC* (automatic volume control) on or off. *AVC* is disconnected with the toggle thrown to the right.

Above this switch is the audio gain control, which is wired into the output of the diode detector and serves, therefore, to control audio volume when using either headphones or speaker.

The *S* meter for indicating carrier intensity or signal strength is in the upper left-hand corner. Just below it, and to the left, is a push-switch which connects the meter in the circuit.

e. Operating Instructions: Phone or Broadcast Reception.—In receiving phone signals, the *AVC* may or may not be used, as desired. If it is not used, we suggest operating the audio gain control about halfway on and controlling the sensitivity with the radio-frequency gain control. If the operator prefers a "quiet" receiver, the audio control may be operated at 1 or 2. If *AVC* is used (left-hand toggle thrown to the left), the radio-frequency gain control may be turned all the way on, that is, to 10, and the volume controlled by the audio gain control only. The setting of the two gain controls is largely a matter to be determined by the preference of the operator and by receiving conditions. If, for instance, local noise or atmospheric static is high, it will be desirable to retard the radio-frequency gain control when using *AVC* so that the sensitivity of the receiver will be held to a definite maximum. If the *CW* oscillator is to be used for locating carriers, as mentioned above, the *AVC* switch must be in the off position (to the right). Turning on the *CW* oscillator with the *AVC* on will block the receiver, making reception of anything but extremely strong signals impossible.

f. CW Reception.—When receiving *CW* signals, the *CW* oscillator must be turned on and the *AVC* switch turned off. Best signal-to-noise ratio will usually be obtained by retarding the audio gain control considerably and controlling sensitivity with the radio-frequency gain control. Turning on the *CW* oscillator switch will, of course, result in a considerable increase in circuit noise. When the control is

turned back and forth, the characteristic pitch of this noise will change. When the characteristic pitch is fairly high, the semi-"single-signal" properties of the receiver are very pronounced, one side of the audio beat note being several times as loud as the other.

g. Phone Reception Using the Crystal Filter.—The use of the crystal filter in phone reception is recommended, particularly when the operator must contend with heavy interference, static, and heterodynes. Since such conditions prevail at most times in the amateur phone bands, the filter will be found particularly useful to amateur phone operators. To receive a phone signal when using the crystal filter, the filter is switched in by means of the phasing control and the phasing dial set at approximately mid-scale. The selectivity control is then adjusted for minimum selectivity, as indicated by maximum noise as the control is rotated back and forth. All phone signals will be reduced in volume, making it necessary to advance both audio and radio-frequency gain controls. The signals may then be tuned in in the usual manner, but it will be found that the selectivity is very high, with the result that all audio-frequency side bands above a few hundred cycles are comparatively weak. Normally, this would result in low intelligibility of the received signal, but since the background noise, static, etc., have been correspondingly reduced, the net result is usually an improvement.

The principal advantage of the crystal filter, however, is its ability to eliminate heterodynes. Suppose, for instance, a signal has been carefully tuned in with reasonably good intelligibility and during the transmission an interfering station comes on, causing a bad heterodyne or inverted speech, ordinarily the desired signal would be "smearcd," but careful adjustment of the phasing condenser will eliminate the heterodyne and the interfering station, in most cases, completely. Intelligibility will remain practically as good as before the interfering station came on.

From a practical standpoint, it is important that the crystal filter be used most of the time where such interference is apt to be encountered, as it is often impossible to switch on the crystal filter and retune the desired signal through the heterodyne. The phasing adjustment will remove one signal only. If another interfering station comes on, however, only one heterodyne will be present, instead of the several resulting from three station carriers beating together.

h. CW Reception with the Crystal Filter.—To use the crystal filter for CW reception, the filter is switched in by means of the phasing control and the phasing condenser set about mid-scale. The AVC switch must be off and the CW oscillator turned on. Advancing the radio-frequency and audio gain controls will result in a hollow, ringing sound the pitch of which will depend upon the setting of the C-W oscillator dial. The actual pitch is not important as long as it is near the middle of the audio range, where the loud-speaker or phones have good sensitivity.

When a signal is picked up, it will be found that as the receiver is tuned slowly across the carrier the beat note will be very sharply peaked at the same pitch as that of the ringing noise, previously mentioned. All other parts of the beat note will be extremely weak and, furthermore, this peak will be found to occur on only one side of the audio beat note. The sharpness of the peak is determined by the selectivity control (upper right-hand knob). At maximum selectivity, the peak is so sharp that it may be hard to find, whereas at minimum selectivity the peak will be very broad. If a signal is being received, after having been properly tuned in, and an interfering station comes on, the resulting heterodyne and interference may be eliminated by adjustment of the phasing condenser. This phasing adjustment is effective in eliminating interference, regardless of the setting of the selectivity control.

i. S Meter.—The S meter serves to indicate the strength of a received signal. It is calibrated from 1 to 9 in arbitrary units which correspond, roughly, to the definition of the nine points of the S scale of the RST system of amateur signal reports. A comparison of the amateur system with the commercial system is as follows; it will be

noted that the commercial scale does not extend beyond the number 5, whereas the amateur scale extends to 9:

Commercial (Used with Q Code)	Amateur (Used with RST System)
QSA 1—signal strength scarcely perceptible	1—signal faint barely perceptible
QSA 2—signal strength weak	2—very weak signals
QSA 3—signal strength fairly good	3—weak signals
QSA 4—signal strength good	4—fair signals
QSA 5—signal strength very good	5—fairly good signals
	6—good signals
	7—moderately strong signals
	8—strong signals
	9—extremely strong signals

Probably no two operators will agree on just how strong a signal must be to warrant an S9 report. After making measurements on a large number of amateur signals, the present meter scale was chosen and intended by the manufacturer

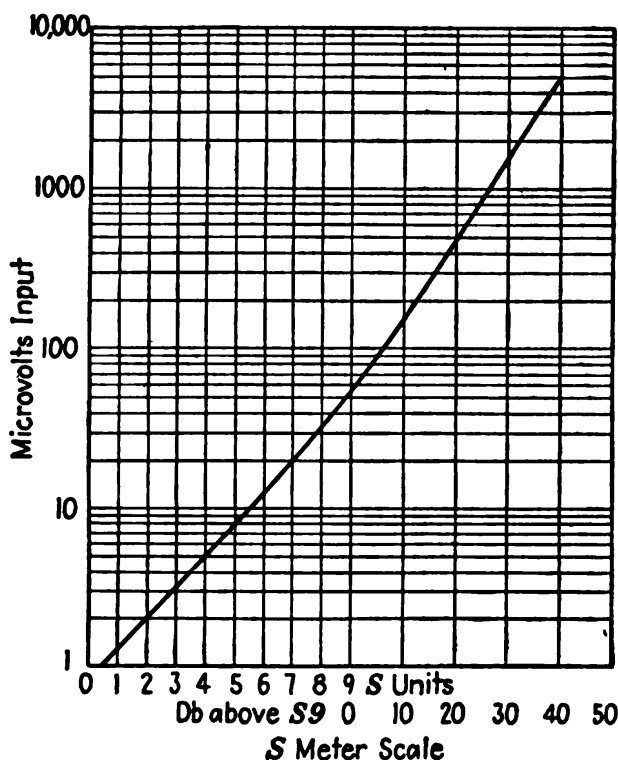


FIG. 5-42.—S-meter scale. (Courtesy of the National Co., Inc.)

amateur use. An approximate conversion to the commercial scale could be had by dividing the meter reading by two. For example, a meter-scale reading of 8 would probably be equivalent to a commercial signal of QSA 4 as indicated in the above scale.

The accompanying curve (Fig. 5-42) shows the relation between average meter readings and the actual signal input to receiver in microvolts, and from this curve will be noted that each S unit is equal to a change of approximately 4 db. The 40-range above the S9 level is used for comparative checks on extremely strong signals.

Figure 5-40 shows the S meter network connected in the B supply circuit to the radio frequency and intermediate-frequency stages. Actually the meter is the indicator

a bridge circuit, three legs of which are fixed resistors, and the fourth (variable) leg the plate circuits of the *AVC* controlled tubes. The bridge is balanced by means of the manual radio-frequency gain control, which, through its action of indirectly changing the plate resistance of the tubes, automatically adjusts the radio-frequency and intermediate-frequency gain to a predetermined level at the same time that the meter is brought to zero. The strength of the incoming signal is, therefore, accurately indicated by the action of the *AVC* circuits in controlling high-frequency gain.

Before making a measurement on a signal, certain adjustments must be made. Since the meter is actuated by the amount of signal reaching the second detector, it is obviously necessary that the receiver be adjusted to have a predetermined amount of amplification between the antenna and second detector. To adjust the amplification to the proper value, the *AVC* switch must be off, the *C-W* oscillator off, the crystal filter off, and the selectivity control set for maximum sensitivity. Now press the meter switch and advance the radio-frequency gain control until the meter comes to 0. The radio-frequency gain dial will read about $9\frac{1}{2}$. The receiver is now adjusted, and the strength of any signal may be measured by throwing the *AVC* switch on and tuning for maximum meter deflection. The audio gain control does not have any effect on the radio-frequency circuit adjustments or upon the meter reading, so that it may be retarded as much as necessary to prevent audio overload when making the preliminary adjustments.

If the signal being measured is extremely strong, however, or if local noise is exceptionally high, it may be impossible to bring the meter to 0. In this case, it is necessary to detune the receiver from the signal or to disconnect the antenna. The above procedure will hold true when checking either phone or *C-W* stations. It is, however, impossible to obtain a continuous check on *C-W* signals, as the beat oscillator must be off.

If it should happen that the S-meter network gets out of balance, the alignment procedure is as follows. Disconnect the antenna and turn off the *AVC*, set the radio-frequency gain control at $9\frac{1}{2}$, then, by means of a screw driver, adjust control 17 (not shown) until the meter reads 0. This control is located in the chassis in back of the meter near the antenna binding post.

i. Coil Ranges.—Four plug-in coil assemblies are supplied as standard equipment for the HRO receiver, each assembly consisting of three radio-frequency coils and one oscillator coil, all individually shielded and provided with built-in trimmer condensers. Calibration curves are mounted on the front of each assembly.

The four assemblies cover all frequencies between 1.7 and 30 megacycles, the division being as follows:

1.7– 4.0
3.5– 7.3
7.0–14.4
14.0–30.0

Inspection of the coil terminal panels will show several small rectangular metal pieces. There are two of these pieces or terminal blocks on each of the coil panels. A small flat-head machine screw will be found in the left-hand terminal block of each coil, looking at the assembly from the front. With the screws in the left-hand position, the coil range will be that shown in the left-hand, or general coverage, chart. If it is desired to change the calibration to amateur band spread, as shown on the right-hand chart of each coil-assembly unit, it is only necessary to move the four screws to the right-hand terminal block of each coil.

In addition to the coils furnished as standard equipment, other assemblies are available, covering frequencies from 2.05 megacycles to 50 kilocycles.

5.28. Ultra-short-wave Receivers.—This type of receiver is the latest development in the radio-receiver field and, therefore, will not attain stability of design until the very high frequencies come into extensive use. As long as there is a scarcity of transmitting stations in these spectrums, and interference is not a problem, the superregenerative circuit commonly used in this service will continue to be satisfactory. However, as transmitting stations increase, and interference results, a more selective receiver will be necessary. The superheterodyne circuit holds promise of being most suitable for ultra-high-frequency work if crystal-controlled transmitters are employed.

A practical adaptation of the superheterodyne circuit in an ultra-short-wave receiver is the RCA Victor receiver especially designed for police and other short-distance communication services. This receiver

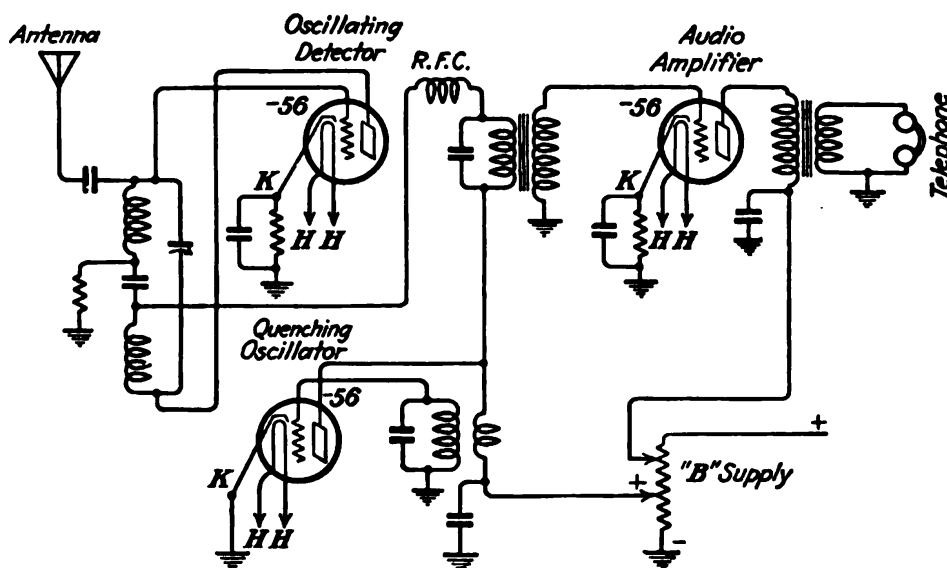


FIG. 5-43.—Superregenerative ultra-high-frequency receiver.

utilizes a circuit of the conventional type as shown schematically in Fig. 5-43.

This receiver employs three type 56 tubes, one as an oscillating detector, one as a quenching oscillator, and one as an audio oscillator.

A cathode short-circuiting switch (not shown) is in the detector circuit which, when closed, causes the circuit to function as a superregenerative receiver and which, when open, biases the detector enough to stop oscillation. Under these conditions the circuit operates as a biased detector and an audio amplifier for monitoring purposes.

High-impedance (20,000 ohms) headphones are used for both receiving and monitoring purposes, and the output circuit from the last audio tube is designed accordingly.

III. RADIO-FREQUENCY-VOLTAGE AMPLIFIERS

5.29. Radio-frequency voltage amplifiers are of two general types: the antenna circuit which follows the receiver antenna and precedes the first-

amplifier grid, and the radio-frequency interstage circuit which operates from a vacuum tube and supplies signal voltage to a following amplifier tube grid. Only the first named type will be treated here.

Antenna circuits may be subdivided into three main classes:

- a. Circuits operating from capacitance antennas (in general these are circuits operating below 2 or 3 megacycles).
- b. Circuits operating from resistance antennas (usually above 2 or 3 megacycles).
- c. Loop antennas.

1. CAPACITANCE ANTENNA CIRCUITS.—A single-wire vertical antenna which is less than one-eighth wave length long may be represented by the circuit shown in Fig. 5-44. By Thévenin's theorem, this may be resolved into an equivalent circuit as shown in Fig. 5-45. The voltage e is the product of the field strength in microvolts per meter and the effective height of the antenna in meters (usually about 75 per cent of actual height). The capacitance C is the total capacitance of the antenna to ground. The impedance Z is the input impedance of the receiver.

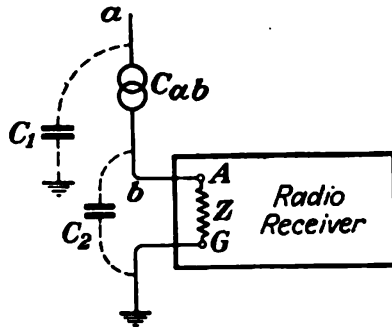
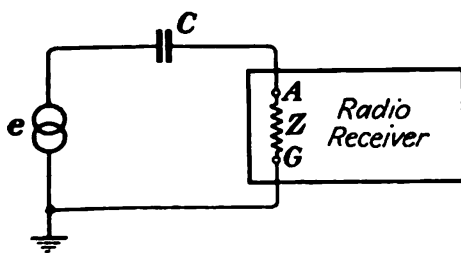


FIG. 5-44.—Capacitance antenna.



$$e = E \times h \text{ microvolts.}$$

C = total capacitance antenna to ground ($C_1 + C_2$, Fig. 5-44).

E = field strength in microvolts per meter.

h = effective height of antenna in meters.

FIG. 5-45.—Equivalent circuit of capacitance antenna.

These circuits fall into five specific types as follows:

1. High-impedance capacitance coupling.
2. Low-impedance capacitance coupling.
3. High-impedance mutual coupling.
4. Low-impedance mutual coupling.
5. Complex coupling.

a. High-impedance Capacitance Coupling.—This antenna circuit is perhaps the simplest from the standpoint of design and analysis. A schematic diagram is shown in Fig. 5-46. Figure 5-47 is the equivalent circuit of this amplifier as obtained from the equivalent antenna circuit shown in Fig. 5-45.

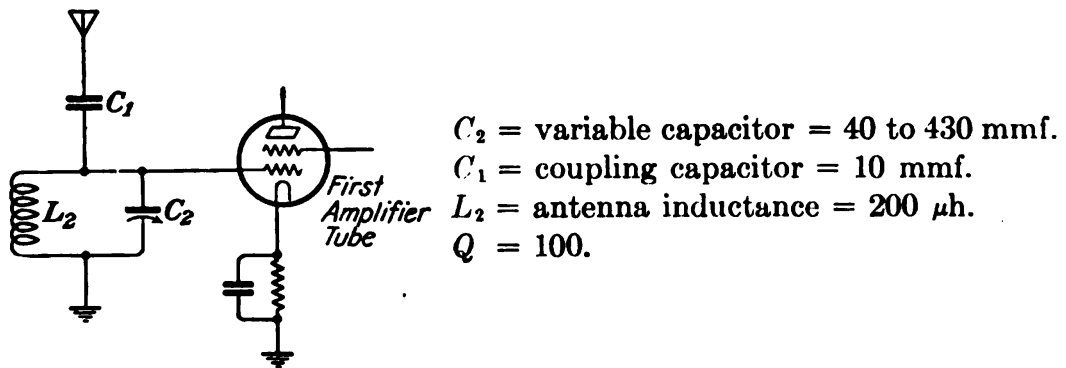


FIG. 5-46.—High-impedance capacitance-coupled antenna circuit.

The gain of this antenna circuit (Fig. 5-47) may be derived from the fundamental consideration that

$$e_2 = Qe_1 \quad (31)$$

where $Q = \omega L_2 / R$.

$$\omega = 2\pi f.$$

R = resistance of L_2 .

$$e_1 = e \frac{C_1}{C_1 + C_2}$$

$e = E \times h$ microvolts (See Fig. 5-45).

C = total capacitance antenna to ground, $C_1 + C_2$, (See Fig. 5-44).

$$\text{Gain} = \frac{e_2}{e} = Q \frac{C_1}{C_1 + C_2} \text{ (derived below)} \quad (32)$$

The selectivity of this circuit near resonance is a function entirely of the Q of the inductance L_2 , and a universal curve of this selectivity is shown in Fig. 5-48.

Selectivity of this circuit to signals far removed from resonance is a function of the Q and of the manner in which the voltage is introduced. A typical curve for an antenna circuit tuned to 1,000 kilocycles is shown in Fig. 5-49.

A curve of gain versus frequency for this circuit is shown in Fig. 5-50. This circuit as designed to cover the broadcast band from 540 to 1,600 kilocycles is shown in Fig. 5-45.

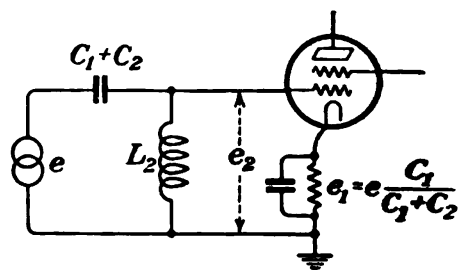


FIG. 5-47.—Equivalent circuit to preceding diagram.

It may be seen from these curves that the gain of this circuit varies directly with frequency squared over any particular band. Also the

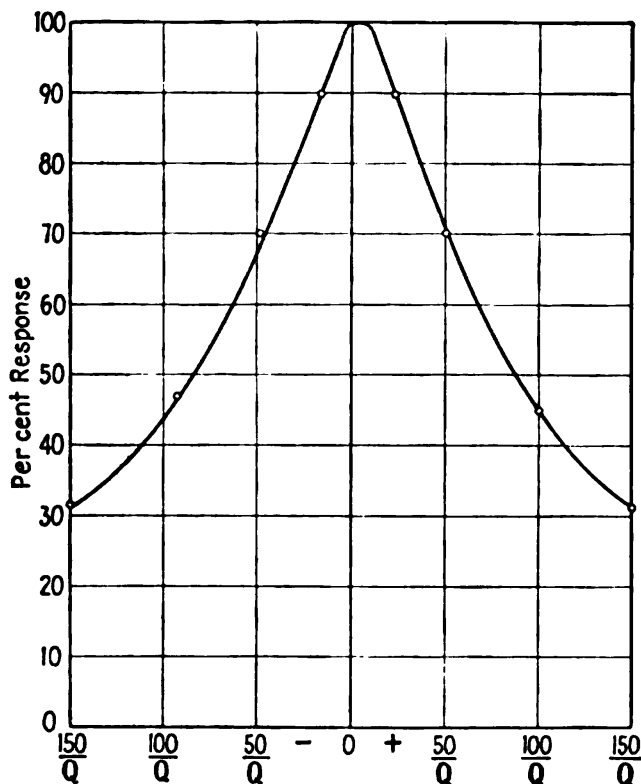


FIG. 5-48.—Universal resonance curve.

image attenuation never exceeds the value of Q regardless of what intermediate frequency is used. An intermediate frequency of 460 kilocycles produces an image attenuation of 80, or within 20 per cent of the maxi-

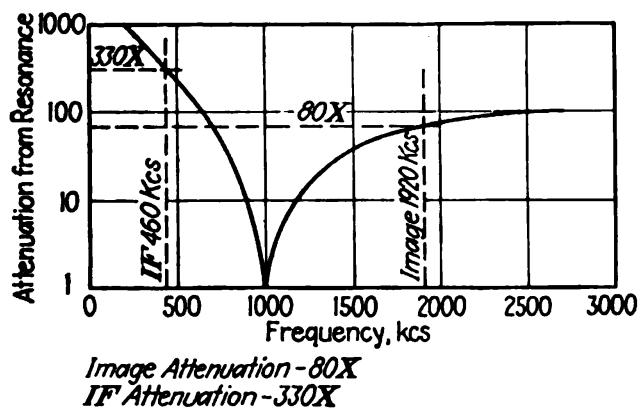


FIG. 5-49.—Selectivity curve.

imum of 100. The intermediate-frequency attenuation, on the other hand, can exceed Q by a considerable amount and is 330 for a 460-kilocycle intermediate frequency.

This type of antenna circuit has two principal disadvantages: the gain varies with frequency squared, and the tuning may be somewhat shifted by variation in antenna capacitance. Offsetting this, it has the advantage of simplicity.

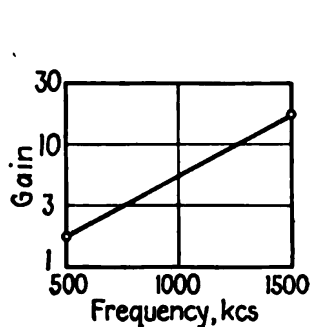


FIG. 5-50.—Gain versus frequency for circuit shown in Fig. 5-49.

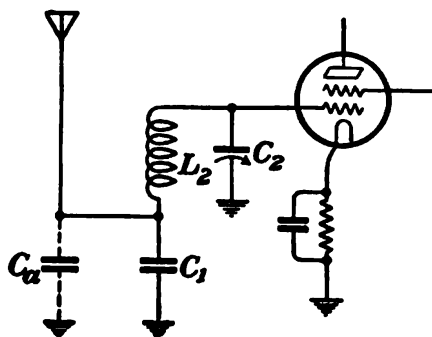


FIG. 5-51.—Low-impedance capacitance-coupled antenna circuit.

b. Low-impedance Capacitance Coupling.—A schematic diagram of this type of antenna circuit is shown in Fig. 5-51. This circuit may be simplified into the equivalent circuit shown in Fig. 5-52.

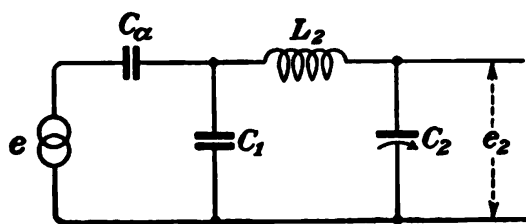


FIG. 5-52.—Equivalent circuit to preceding diagram.

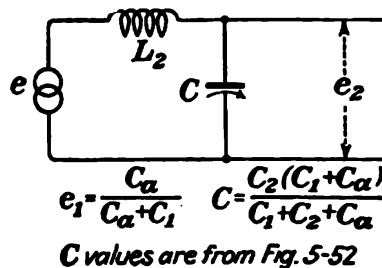


FIG. 5-53.—Circuit for gain calculator.

By application of Thévenin's theorem, this may be further simplified to the circuit shown in Fig. 5-53. The gain may be calculated by dividing the output voltage e_2 by the input voltage e_1 .

$$\text{Circuit gain} = \frac{e_2}{e_1} \quad (33)$$

$$\text{where } e_1 = e \frac{C_a}{C_a + C_1}$$

$$e_2 = Qe_1 = Qe \frac{C_a}{C_a + C_1}$$

$$\text{Over-all gain} = \frac{Qe \frac{C_a}{C_a + C_1}}{e} = Q \frac{C_a}{C_a + C_1} \quad (34)$$

In most such antenna circuits, the antenna capacitance C_a is small compared with the coupling capacitance C_1 . In this case, the gain for-

mula simplifies to

$$\text{Gain} = Q \left(\frac{C_a}{C_1} \right) \quad (35)$$

It may be seen from this formula that the gain is dependent on only three factors: Q , antenna capacitance C_a , and coupling capacitance C_1 .

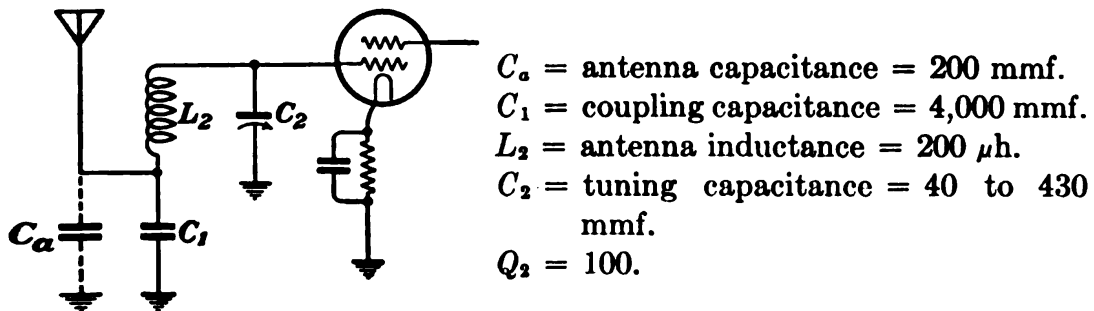


FIG. 5-54.—Typical low-impedance capacitance-coupled antenna circuit.

In general, these values remain nearly constant over any tuning range, and as a result the gain remains nearly constant. The gain, however, does depend directly on the antenna capacitance C_a , which is somewhat of a disadvantage. In the high-impedance capacitance-coupled antenna circuit, the gain was independent of the antenna capacitance over quite a wide range of variation.

Selectivity in the immediate vicinity of resonance is directly dependent on the Q of L_2 and may be determined from the universal resonance curve, Fig. 5-48. In this respect, the high- and low-impedance capacitance-coupled antenna circuits are identical.

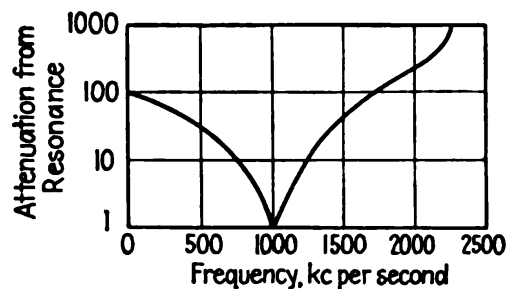


FIG. 5-55.—Selectivity curve of low-impedance capacitance-coupled antenna circuit when $Q = 100$.

At frequencies far removed from resonance, the selectivity depends upon the Q and the manner in which the voltage is introduced. Figure 5-54 shows a typical antenna circuit designed to cover the broadcast band from 450 to 1,600 kilocycles.

The gain may be found from the formula

$$\text{Gain} = Q_2 \frac{C_a}{C_1} = 100 \times \frac{200}{4,000} = 5$$

A selectivity curve of this circuit at 1,000 kilocycles for frequencies far removed from resonance is shown in Fig. 5-55.

From this curve, it may be determined that the image attenuation for an intermediate frequency of 460 kilocycles is 220 times and the intermediate-frequency attenuation is 80 times. It is apparent that the IF attenuation may never exceed the value of Q , whereas the image attenuation may be several times that value for high intermediate frequencies. This contrasts with the high-impedance capacitance-coupled antenna circuit where the reverse is true.

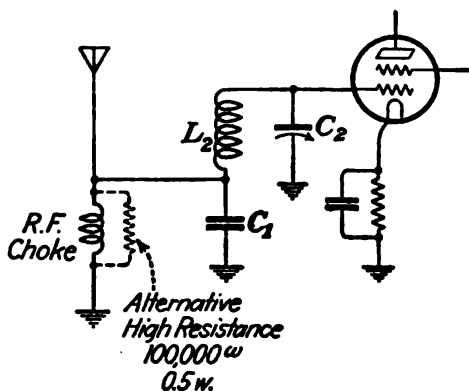


FIG. 5-56.—Practical circuit to remove hum modulation.

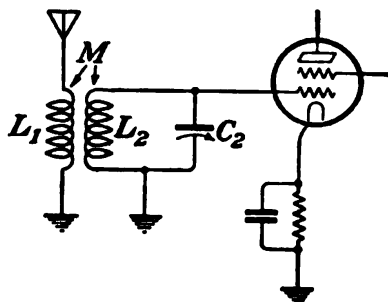


FIG. 5-57.—High impedance mutual coupled antenna circuit.

Considerable use is found for this type of antenna circuit in applications where the antenna capacitance remains constant, such as automobile or aircraft radios. It likewise has the advantage of simplicity. It has the disadvantage that no direct-current connection exists from grid to ground on the first amplifier tube. This is usually provided by a choke coil or high resistance as shown in Fig. 5-56. Such a connection effectively removes any possibility of hum modulation caused by stray coupling to power lines or other 60-cycle circuits.

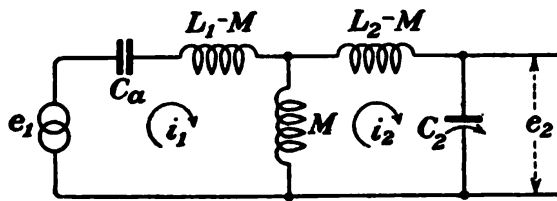


FIG. 5-58.—Equivalent circuit to preceding diagram.

c. High-impedance Mutual-coupled Antenna.—This is the most widely used antenna circuit for use with a separate antenna and is also called *inductive coupling*. The primary resonant frequency is below the tuning range. A schematic diagram of such a circuit is shown in Fig. 5-57.

The equivalent circuit of this antenna circuit may be derived by consideration of Thévenin's theorem and by use of the equivalent circuit of a two-winding transformer. This is shown in Fig. 5-58.

The gain for this circuit as determined by solution of two simultaneous mesh equations is

$$\text{Gain} = \frac{e_2}{e_1} = MQ_2 \frac{\omega^2 C_a}{\omega^2 L_1 C_a - 1} \quad (36)$$

where M = mutual inductance in henrys.

$Q_2 = \omega L_2 / R_2$ (Q of the secondary inductance).

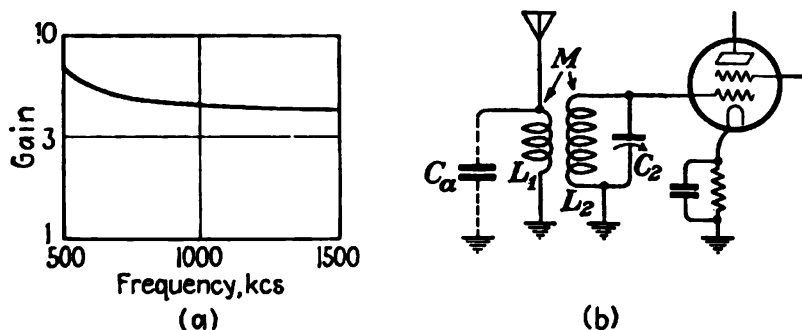
L_1 = primary inductance in henrys.

C_a = antenna capacitance in farads.

The term $\omega^2 L_1 C_a$ is unity at the resonant frequency of the primary. For this type of circuit, the primary resonance is usually about one-half the lowest tuning frequency. Hence, for the broadcast band 540 to 1,600 kilocycles, a primary resonance of about 270 kilocycles is normally used. This means that the term $\omega^2 L_1 C_a$ is large compared with unity throughout the tuning range. With this simplification, the following approximate gain formula results:

$$\text{Approximate gain} = \frac{MQ_2}{L_1} \quad (37)$$

A typical curve of gain versus frequency for this antenna circuit is shown in Fig. 5-59.



L_1 = primary inductance = 2 mh.

L_2 = secondary inductance = 200 μ h.

C_a = antenna capacitance = 200 mmf.

f_p = primary resonance = 250 kilocycles

M = mutual inductance = 100 μ h.

Q_2 = 100.

FIG. 5-59.—Gain curve and antenna circuit.

Gain, calculated from the approximate formula, for the circuit shown in Fig. 5-59(b) is

$$\text{Gain} = \frac{MQ_2}{L_1} = \frac{100 \times 10^{-6} \times 100}{2,000 \times 10^{-6}} = 5$$

The selectivity of this antenna circuit near resonance depends on Q in exactly the same manner as all the other circuits, except that the Q is

reduced somewhat by the presence of the tuned primary. This reduction in Q is approximately equal to $2k^2$, or

$$Q_2^1 = (1 - 2k^2)Q_2 \quad (38)$$

where Q_2 = secondary Q (primary removed).

Q_2^1 = effective secondary Q (primary present).

k = coefficient of coupling, primary to secondary.

The selectivity at frequencies far removed from resonance is effected by the tuned primary as well as the secondary. An exact solution for this selectivity is too complex to be of any practical use. In general, the selectivity for frequencies higher than the signal is improved by the primary, whereas the selectivity for frequencies lower than the signal is impaired. This usually means that the image attenuation is good, whereas the intermediate-frequency attenuation is relatively poor.

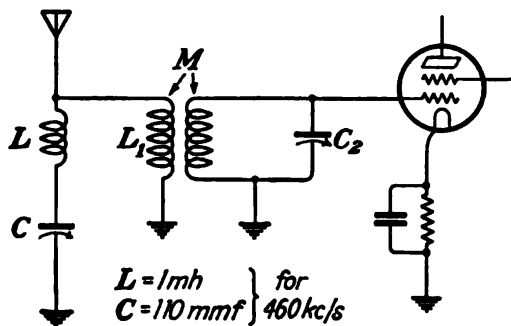


FIG. 5-60.—Circuit to improve intermediate-frequency rejection.

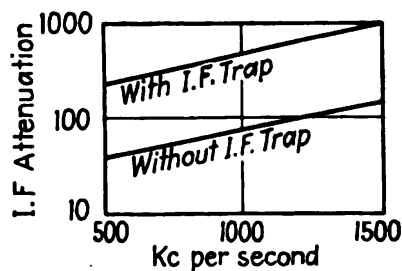


FIG. 5-61.—Intermediate rejection for circuit shown in Fig. 5-60.

The IF attenuation may be considerably improved by use of an IF wave trap. Such a circuit (L and C) is shown in Fig. 5-60.

The performance of the rejection circuit may best be shown by a curve of intermediate-frequency rejection as a function of frequency with and without the trap circuit connected. A curve for the circuit shown appears in Fig. 5-61.

This type of antenna circuit has several advantages over other types. As may be seen from the formula, gain is practically independent of both frequency and antenna capacitance. This is particularly desirable when a receiver is to operate from several different antennas. Good image attenuation may be obtained, and by use of the intermediate-frequency trap, the intermediate-frequency rejection may be made satisfactory.

d. Low-impedance Mutual-coupled Antenna.—This type of antenna has the same schematic diagram and the same equivalent circuit as the high-impedance circuit (Figs. 5-57 and 5-58). It differs in that its primary resonance is above the tuning range.

Solution of the equivalent circuit shown in Fig. 5-58 for gain yields the equation

$$\text{Gain} = \frac{MQ_2\omega^2 C_a}{\omega^2 L_1 C_a - 1} \quad (39)$$

Since the primary is resonant above the tuning range (usually about twice the highest tuning frequency), the term $\omega^2 L_1 C_a$ is considerably less than unity through the tuning range and may be neglected. This simplification yields the following approximate gain formula.

$$\text{Approximate gain} = MQ_2\omega^2 C_a \quad (40)$$

where M = mutual inductance in henrys.

$Q_2 = \omega L_2 / R_2$ (Q of the secondary inductance).

$\omega = 2\pi f$ (frequency in cycles).

C_a = antenna capacitance in farads.

A typical antenna circuit designed to cover the broadcast band from 540 to 1,600 kilocycles is shown in Fig. 5-62.

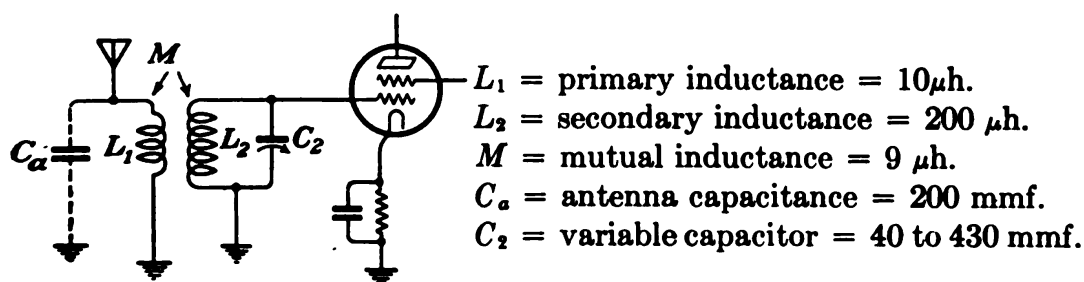


FIG. 5-62.—Typical low-impedance mutual-coupled antenna circuit.

The gain of this circuit varies directly with the antenna capacitance and with the frequency squared. This is a distinct disadvantage since the receiver may be operated on widely different antennas, giving different results on each. Also the sensitivity of the receiver may vary by as much as the ratio of maximum frequency to minimum frequency squared. For the broadcast band from 540 to 1,600 kilocycles, this is about 9:1. A curve of the gain of the circuit shown in Fig. 5-62 plotted as a function of frequency is shown in Fig. 5-63.

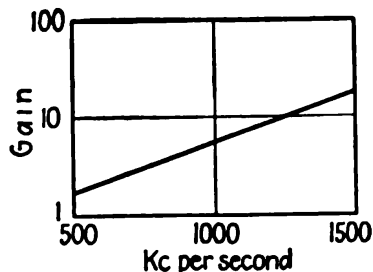


FIG. 5-63.—Antenna gain curve for preceding diagram.

The selectivity of this circuit near resonance is determined from the universal resonance curve. At frequencies far removed from resonance, the selectivity of this antenna circuit causes good attenuation of low frequencies and poor attenuation of high frequencies. This results from the primary resonance being above the tuning range. It results in good intermediate-frequency attenuation and poor image attenuation. Unfor-

tunately it is very difficult to build a trap circuit for image frequencies since some of them may fall within the tuning range. For this reason, and others pointed out previously, this antenna circuit finds only limited application.

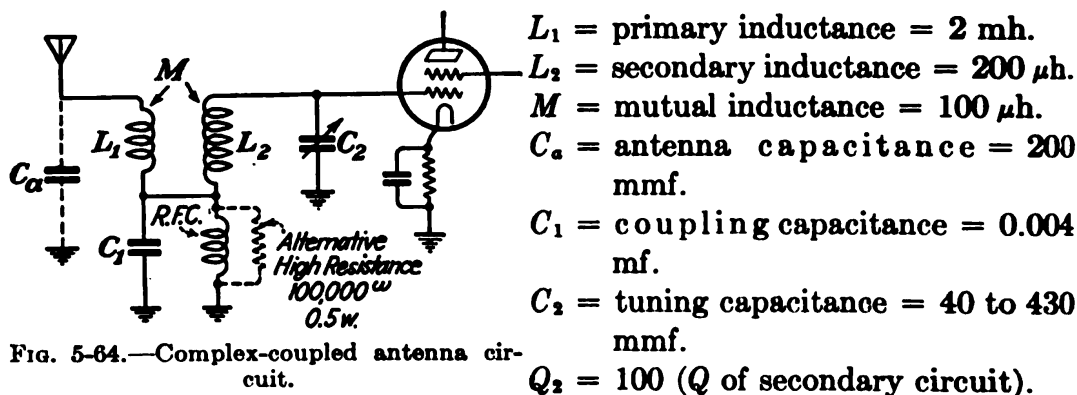


FIG. 5-64.—Complex-coupled antenna circuit.

e. Complex-coupled Antenna Circuits.—The most widely used circuit of this type is the combination of low-impedance capacitance and high-impedance mutual coupling as shown in Fig. 5-64. An equivalent of this antenna is shown in Fig. 5-65.

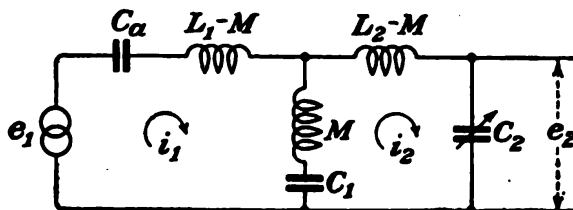


FIG. 5-65.—Equivalent circuit to preceding diagram.

Solution of this equivalent circuit for gain yields the relation

$$\text{Gain} = \frac{e_2}{e_1} = M \pm \left(\frac{1}{\omega 2C_1} \right) \frac{Q_2 \omega^2 C_a}{\omega 2L_1 C_a - 1} \quad (41)$$

This formula is the same as the gain formula for a mutual-coupled antenna circuit, except that the value of M is replaced by $M \pm \left(\frac{1}{\omega 2C_1} \right)$. The plus or minus sign results from the mutual coupling aiding or bucking the capacitance coupling. This is determined by the phasing of the coils.

Simplification of this formula yields the following relation for gain:

$$\text{Approximate gain} = M \pm \left(\frac{1}{\omega 2C_1} \right) \frac{Q_2}{L_1}$$

The gain of this circuit depends on both antenna capacitance and frequency. The gain varies inversely with both these factors, and the amount of variation depends on the relative magnitudes of the mutual coupling M and the capacitance coupling $1/\omega 2C_1$. A gain curve for a

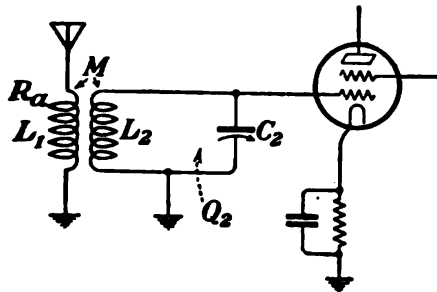
typical antenna circuit designed to cover the broadcast band (540 to 1,600 kilocycles) is shown in Fig. 5-66.

The selectivity characteristics of this circuit are similar to those of the high-impedance mutual-coupled antenna circuit. An intermediate-frequency trap is usually required to improve the intermediate frequency attenuation.

This circuit is used where large antenna gains are required, particularly at the low-frequency end of the band. It finds considerable application in automobile radio receivers.

2. RESISTANCE ANTENNA CIRCUITS.—Antennas operating at or near their resonant frequency act as a resistance. The equivalent circuit of such an antenna becomes simply a voltage acting in series with a resistance.

A typical antenna circuit designed to cover the frequency range from 6 to 18 megacycles is shown in Fig. 5-67. It incorporates a primary inductance for coupling.



- L_1 = primary inductance = $20 \mu\text{h}$.
- L_2 = secondary inductance = $2 \mu\text{h}$.
- M = mutual inductance = $1.5 \mu\text{h}$.
- C_2 = variable capacitance = 50 to 430 mmf.
- Q_2 = 100 (Q of secondary inductance).
- R_a = antenna resistance = 300 ohms.

FIG. 5-67.—Resistance-antenna circuit.

The gain of this circuit, as determined by solution of its equivalent circuit, is given by the expression

$$\text{Gain} = \frac{k \sqrt{\frac{L_2}{L_1}} Q_2}{\frac{1}{Q_1} \pm j \pm k^2 Q_2} \quad (42)$$

where L_1 = primary inductance in henrys.

L_2 = secondary inductance in henrys.

k = coefficient of coupling.

$Q_1 = \omega L_1 / R_a$.

R_a = antenna resistance in ohms.

$Q_2 = \omega L_2 / R_2$ (Q of secondary circuit).

$j = \sqrt{-1}$.

A curve of gain versus frequency for the antenna circuit in Fig. 5-67 is shown in Fig. 5-68.

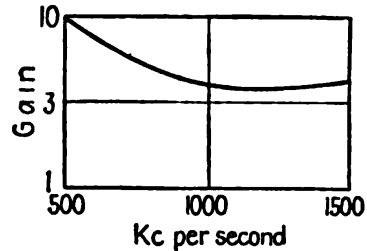


FIG. 5-66.—Antenna gain curve for broadcast band.

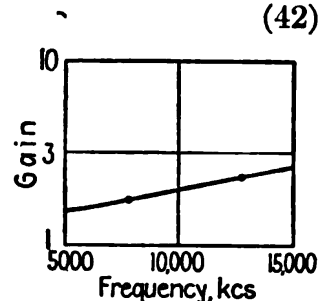


FIG. 5-68.—Antenna gain curve for preceding diagram.

At ultra-high frequencies (above 20 megacycles), the input impedance of a vacuum tube becomes a relatively low resistance. At these frequencies, the loss in the antenna coil itself is usually small compared with the loss in the input loading resistance of the tube. The equivalent circuit is shown in Fig. 5-69.

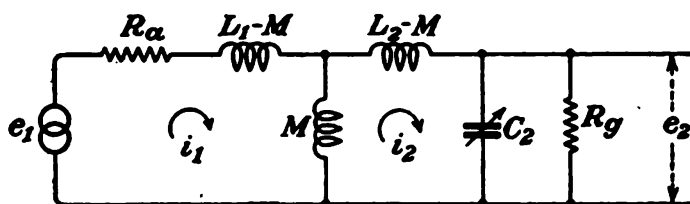


FIG. 5-69.—Equivalent circuit of ultra-high-frequency antenna input.

The input loading resistance for the first tube R_g absorbs most of the power supplied from the antenna, e_1 , and R_a . Maximum antenna gain, therefore, occurs when R_g is reflected back through the transformer to match R_a . This means that

$$R_a = \frac{R_g}{(\text{voltage ratio})^2} \quad (43)$$

or

$$\text{Transformer voltage ratio} = \sqrt{\frac{R_g}{R_a}} \quad (44)$$

Since e_1 is applied in series with R_a , and since the antenna resistance is matched by the reflected input loading resistance of the first tube, a voltage of only $0.5e_1$ appears across the transformer input. The gain as defined by e_2/e_1 is therefore only one-half the voltage ratio, or

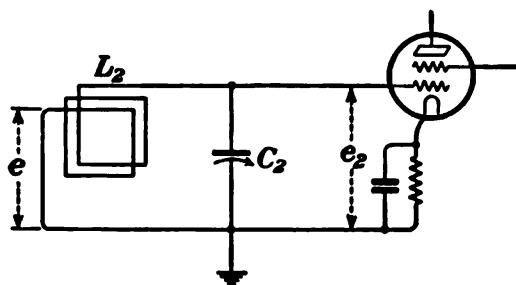


FIG. 5-70.—A typical tuned loop antenna circuit.

$$\text{Gain} = 0.5 \sqrt{\frac{R_g}{R_a}} \quad (45)$$

For a typical input circuit, consider a 6AC7 first-amplifier tube operated at 50 megacycles from a 100-ohm transmission line. The input loading resistance is approximately 3,000 ohms at this frequency. Maximum gain is therefore

$$\text{Gain} = 0.5 \sqrt{\frac{R_g}{R_a}} = 0.5 \sqrt{\frac{3,000}{100}} = 2.7$$

3. LOOP ANTENNA CIRCUITS.—A typical tuned loop antenna circuit is shown in Fig. 5-70. This type of antenna circuit is complete within itself in that it transforms the radiated energy directly into a voltage

supplied to the grid of the first tube. Its selectivity is determined by the Q of the loop inductance L_2 and may be determined either from the universal resonance curve (Fig. 5-48) or from the selectivity curve shown in Fig. 5-55. As may be seen from this curve, the intermediate-frequency rejection may never exceed the value Q , whereas the image rejection may be several times that value depending on its proximity to the signal frequency.

The voltage per turn induced in a loop antenna is given by the equation

$$\frac{e}{\text{turn}} = \frac{E2\pi LS}{\lambda} \cos \phi = \frac{2\pi EA}{\lambda} \cos \phi \quad (46)$$

where e/turn = induced voltage in microvolts.

E = radiated field strength in microvolts per meter.

A = area of loop in square meters.

L = height of loop.

S = width of loop.

λ = wave length in meters.

ϕ = angle between the line of direction taken by the plane of the loop and the line of direction of the transmitting station.

If the loop has T turns with a ratio of inductive reactance to resistance of Q , the following expression relates the voltage delivered to the grid (e_2) to the circuit constants and the field strength:

$$e_2 = \frac{2\pi EAQT}{\lambda} \cos \phi \quad (47)$$

The loop antenna is widely used in modern broadcast receivers for the broadcast band. Its advantages are its simplicity and ease of installation. Its disadvantages are relatively low voltage delivered to the first grid, as compared with a normal outside antenna, and the difficulty of installing trap circuits to reduce undesired signals.

The directional characteristics of a typical loop antenna are shown in Fig. 5-71. The solid line is the theoretical curve and applies to a well-shielded loop with its only source of energy being the radiated field. The dotted curve shows the effect of stray pickup from power lines and other sources of interference. It is apparent that two sharp nulls exist in the first case and that they disappear when stray pickup exists.

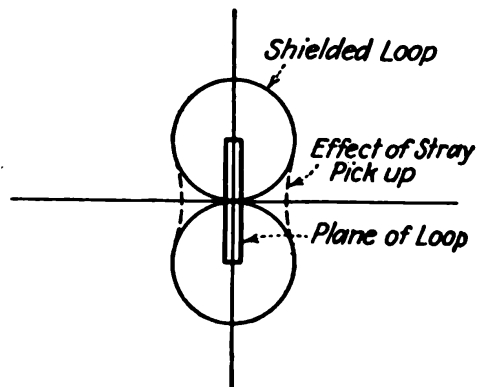


FIG. 5-71.—Directional pattern of loop antenna.

IV. TESTING AND FREQUENCY MEASUREMENTS

5.30. The Cathode-ray Tube. *a. Basic Theory and Operation.*—One of the most important developments of modern radio and electrical science has been the cathode-ray tube. Daily, new uses and applications are being found for this versatile piece of equipment. By its use, it is possible to observe exactly what transpires in any electric circuit, not only under static or steady conditions, but as rapid changes and non-recurring or transient conditions occur. Television and the electron microscope are merely applications of special types of cathode-ray tubes.

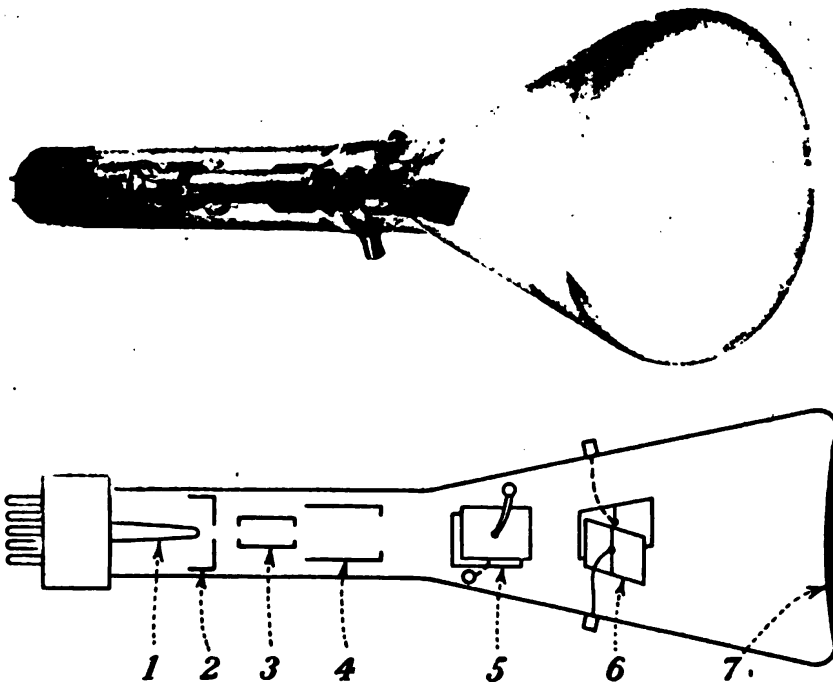


FIG. 5-72.—Cathode-ray tube; (top) photograph; (bottom) cross section.

The most common form of cathode-ray tube, illustrated in Fig. 5-72, is known as the electrostatic deflection type and consists of a highly evacuated glass envelope of the shape shown. Its length may vary from that of an ordinary receiving tube to over 20 in. long and the diameter of its large end from 1 to 20 in.

It consists of a series of electrodes known as the *electron gun*, the leads of which are brought out usually through its base; two sets of deflecting plates, to which connections are made through caps resembling ordinary vacuum-tube grid caps appearing on the outside of the glass bulb; and a screen of luminescent material applied to the inner surface of the large end of the tube upon which the images appear.

The electron gun consists of an indirectly heated cathode (1) such as is found in the usual receiving tube, which when heated emits electrons. The grid (2) functions exactly as in the usual receiving tube to control

the electrode stream and is maintained at a potential negative with respect to the cathode. The first anode (3) which is operated positive with respect to the cathode focuses the electron stream passing through the opening in the grid into a thin beam-like light through the lens of a camera. The second or high-voltage anode (4) which is operated at a potential very positive with respect to the cathode accelerates the electrons so that after passing between the deflecting plates (5) and (6) they strike the screen (7) at a high velocity.

This screen (7) is made of a material (called a phosphor) which has the property of becoming luminous when bombarded by electrons. When the cathode is heated and the electrode voltages of the gun are properly adjusted, a single spot of light will appear where the electron beam strikes.

Since the electrons in the beam are negative, they are attracted by a positive potential and repelled by a negative one. The horizontal deflection plates (5) which are perpendicular to the ground plane and on either side of the electron streams are utilized to move it backward and forward in a horizontal direction by applying a voltage, making one plate positive or negative with respect to the other. The vertical deflection plates (6) which are parallel to the ground plane and between which the electron stream passes while on its way to the screen may be used to move the beam and the resulting spot on the screen in a vertical direction.

Thus it may be seen that by proper choice of potentials applied to the deflecting plates the spot on the screen may be moved to any position on the screen. Now, if the voltages on the plates are changed rapidly, the spot may be caused to move rapidly about on the screen, and because of the persistence of vision and the screen material, lines and figures of any kind may be made to appear.

Now if the voltage that is applied to the horizontal deflecting plates rises at a constant rate and then suddenly drops to relative zero, a saw-tooth wave will be developed as illustrated in Fig. 5-73.

If this voltage is so applied or "phased" that the spot will be swept from the left to the right of the screen and then instantly returns, a line of light will appear horizontally across the screen.

If there is then applied to the vertical deflecting plates (6) a voltage wave whose form it is desired to analyze, say a 60-cycle sine wave, as the linearly rising voltage (*a*) sweeps the spot across the screen the sine wave on the vertical plates will lift it vertically above and depress it below the zero axis or neutral position (usually the center of the screen) sinusoidally. So, depending on the frequency of the applied voltage relative to that of

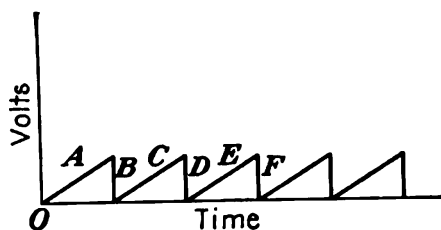


FIG. 5-73.—Characteristics of a saw-tooth wave.

the "saw-tooth" or sweep voltage, that is the number of sinusoidal up and down motions caused by the voltage on the vertical plates occurring during one sweep (*A*) as illustrated in Fig. 5-73, there will be traced on the screen one or more cycles of the applied voltage as in Fig. 5-74.

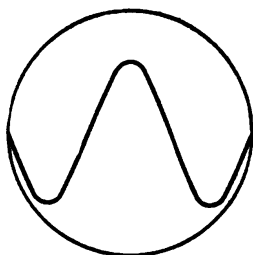


FIG. 5-74.—One and one-half cycles of applied voltage during one cycle of sweep voltage.

Since the spot is returned to the left-hand side of the screen by change in voltage (*B*) of the saw-tooth which occurs almost instantaneously, the return trace is invisible and the sweep voltage (*C*) again scans the outlines of the sine wave on the screen, quickly followed by the return (*D*) and the sweep (*E*), and so on, so that the image caused by the applied voltage on the vertical plates, owing to the persistence of vision and screen, seems to be steady on the screen although it is traced by the racing spot.

By varying the frequency of the sweep, any number of cycles or fractions of a cycle of applied voltage may be made to appear. The wave shape of any complex wave may thus be readily analyzed.

The electron beam is practically devoid of weight and therefore has practically no inertia. Thus, frequencies or rapid transient voltages may be used to deflect it. Since the deflecting plates draw little or no current, their effect on (or loading of) circuits under steady conditions is negligible.

The saw-tooth wave is easily generated by a relaxation oscillator as shown in the simplified schematic diagram of Fig. 5-75.

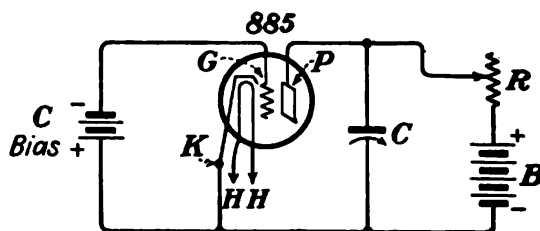


FIG. 5-75.—Saw-tooth relaxation oscillator.

The *B* battery charges condenser *C* through the variable resistor *R* until the plate voltage of the 885 grid-controlled gas tube rises enough to permit the tube to ionize and conduct. Then the condenser discharges rapidly through the tube which during the conducting period is of low impedance. When the plate potential as a result drops below the ionization potential for the particular grid bias applied, the tube again becomes a high impedance and the *B* supply charges the condenser *C*. The charging cycle when applied to the horizontal sweep plate constitutes factors *A*, *C*, *E*, etc., of the saw-tooth wave (Fig. 5-73) and the sudden discharge portions *B*, *D*, *F*, and so on.

The frequency of the relaxation oscillator is determined by the length of time needed to charge and discharge capacitor C which is a function of the value of this capacitor and the resistor R (time-constant = $R \times C$ seconds). A multitude of circuits utilizing various types of tubes both gas filled and vacuum can be used to supply sweep voltages.

If a small alternating-current voltage is introduced in series with the grid of the oscillator voltage, it tends to stabilize the frequency of the oscillator at the frequency of the applied alternating-current voltage



FIG. 5-76.—RCA cathode-ray oscillograph. (Courtesy of RCA Mfg. Co.)

or in some cases at a harmonic or multiple of the alternating-current voltage. This phenomenon is used in cathode-ray oscillographs to keep the image on the screen steady by synchronizing the sweep voltage with the observed voltage. A portion of the incoming voltage applied to the vertical plates is diverted through a voltage-divider network of some sort and applied to the oscillator grid. If it is desired to "sync" the sweep with some external voltage, this can readily be accomplished since most cathode-ray oscilloscopes provide for an external connection.

Figure 5-76 illustrates the front panel and screen view of an RCA cathode-ray oscilloscope. The circular window is the tube screen upon which the images appear. This is often calibrated by being covered with a transparent screen upon which are printed rectangular coordinates.

It is, therefore, possible to use the cathode-ray tube as an excellent vacuum-tube voltmeter, as the deflection of the spot on the screen is proportional to the applied voltage.

The intensity control shown varies the grid bias of the cathode-ray tube and controls the intensity of the electron stream and the brilliance of the image on the screen. The focus control varies the positive potential on the first anode and is used to bring the image to a sharp focus. Vertical and horizontal centering controls vary the fixed direct-current potentials on the deflection plates referred to and enable the image to be moved conveniently about on the screen. A rough and a fine frequency control for the saw-tooth oscillator voltage is provided. A "sync" control enables optimum synchronizing voltage to be applied to the sweep grid circuit. Gain controls and on and off switches for the amplifiers are provided so that weak signal voltages may be applied to the deflection plates in the event that the voltages under observation are in themselves too small to secure adequate deflection.

The switch for the horizontal-deflection amplifier usually provides a position for applying external voltages to this set of plates directly as well as through the amplifier, and also for supplying sweep voltages generated by the sweep oscillator in the "scope" itself, synchronized by a portion of the voltage on the vertical plates. These "timing" voltages feed through the horizontal-deflection amplifier to the horizontal deflecting plates. Still another position applies sweep saw-tooth voltages as before, but synchronized by a portion of the 60-cycle line or power-supply voltage. Finally, a position is provided for an external "sync" voltage.

A pair of binding posts for applying the voltages to the vertical plates are provided, as well as a set of posts for applying the horizontal deflecting voltage, provided that the internal sweep is not used. Another binding post permits the application of an external sweep-oscillator "sync" voltage. The other binding posts shown are supplied merely to assure a common ground for all incoming circuits.

In television and in certain cathode-ray oscilloscopes, electromagnetic instead of the described electrostatic deflection principle is used. The electron stream can be deflected by a magnetic field as well as an electric potential. Thus if, instead of applying voltages to deflecting plates, currents are caused to flow in solenoids placed about the neck of the tube, the resulting magnetic fields will cause essentially the same sort of movement of the spot on the screen as do the electrostatic plates.

The electron gun of a magnetic deflection tube is the same as that of the electrostatic tube, but a "yoke" about the tube neck contains a set of solenoids or coils through which deflecting or sweep currents flow. These cause magnetic fields which achieve substantially the same results as the electrostatic fields in causing images representative of circuit conditions to appear on the screen.

Thus far only the action of the tube when a "saw-tooth" or linear time axis sweep was provided has been considered. But as was mentioned, in the usual commercial oscilloscope provision is made as well to apply external voltages to the horizontal deflecting plates. If the pattern resulting on the screen when a voltage of one frequency and given wave shape is applied to the vertical deflecting plates, and a voltage of another frequency and the same or different wave shape is applied to the horizontal deflecting plates, the patterns on the screen are known as Lissajous figures.

Lissajous Figures.—These figures provide a means of frequency and phase measurement. If an equal sinusoidal voltage of identical frequency, but 90 degrees out of phase, is applied to each set of plates, the result will be a circle as illustrated in Fig. 5-77. Curve *A* is the voltage

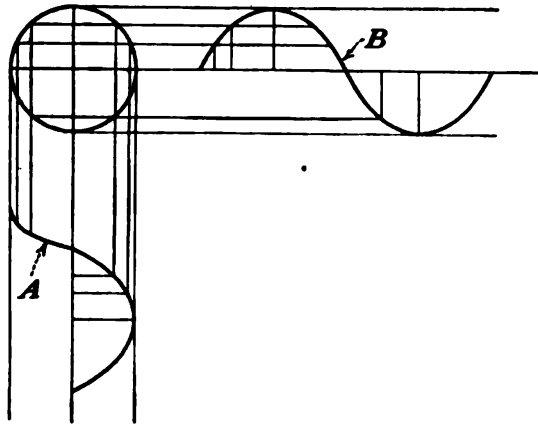


FIG. 5-77.—An equal sinusoidal voltage yields a resultant frequency 90 degrees out of phase.

applied to the vertical deflecting plates, and curve *B* is the voltage applied to the horizontal deflecting plates. If voltages *A* and *B* are in phase, there will be a straight line on the screen. If the phase difference is between 0 degrees and 90 degrees, an ellipse will appear, the amount of phase difference being determined by the ratio of its major and minor axis.

If a voltage of known frequency is applied to the horizontal deflecting plates, it will be possible to determine the frequency of an unknown voltage applied to the vertical deflecting plates by carefully observing the number of loops in the resulting Lissajous figure. As has been seen in the case where the frequency ratio is one to one, a circle or an ellipse appears, except in the limiting case of exactly in phase (or 180 degrees out of phase) where a straight line is seen. Now, if the Lissajous figures are considered as a picture traced on a glass cylinder revolving before the observer's eyes, and the number of loops along one axis are counted and compared with the number of line intersections along the other, and the result expressed as a ratio, it will be possible to determine directly the ratio

of the unknown to the known applied frequency. Figure 5-78 illustrates some Lissajous figures resulting from typical frequency ratios.

c. Distortion and Modulation. Measurements.—The cathode-ray oscilloscope offers a simple means of checking distortion in audio amplifiers. If a sine-wave voltage from a signal generator is fed into the amplifier, the output applied to the vertical deflection plates of the "scope," and a linear timing sweep of frequency, necessary to reproduce two or three cycles on the screen, is applied, any departure of the output wave shape from the known sinusoidal input becomes readily discernible. With properly calibrated attenuators on the signal generator supplying the input, and by simultaneously observing the output on the oscilloscope and output meter, the amount of gain as well as the maximum distortion output at any frequency may be obtained. To keep the pattern steady on the screen, use an internal "sync" or sweep.

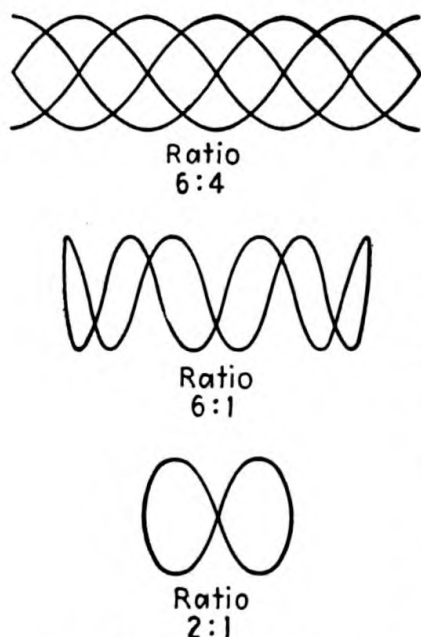


FIG. 5-78.—Lissajous figures.

Radio-telephone stations of all kinds from the simplest amateur ones to the most powerful broadcasting stations may quickly estimate present modulation and show instantly if overmodulation is occurring. A small pickup is placed near the output tank and connected by a simple transmis-

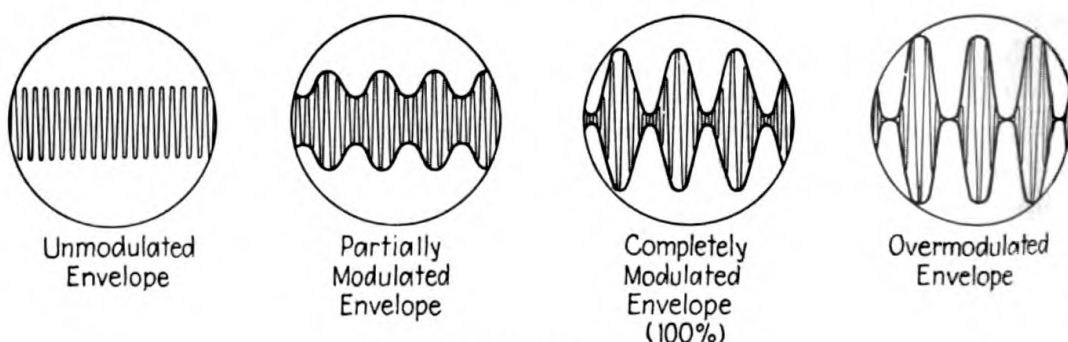


FIG. 5-79.—Modulation pattern.

sion line across a conveniently located parallel resonant circuit. The voltage across the parallel resonant circuit is applied to the vertical deflection plates of a cathode-ray "scope." If sinusoidal input is used for ease of observation, adjust the "timing" frequency of sweep oscillator for two or three audio cycles to appear on the screen. Use the internal "sync" with proper adjustment of the "sync" control to keep the pattern steady.

The radio-frequency voltage will be seen as solid illuminated pattern surrounded by the audio envelope. The observer is actually seeing a radio wave in action. From previously gained knowledge of modulation, the typical patterns shown in Fig. 5-79 are easily identifiable. By comparing the height of the peaks with the unmodulated envelopes, an accurate estimate of modulation percentage can be obtained.

Whenever the input to the modulator consists of regular program material instead of the simple sine waves shown above, the pattern on the screen will be quite complex and continually in motion. The skilled operator soon learns however to estimate percentage modulation, and even the beginner can soon recognize overmodulation "splashes."

Another method of modulation measurement not so generally used involves the application of radio-frequency voltages exactly as in the previous discussion, but this time a small portion of the audio output of the modulator is applied from a voltage divider as "sweep" voltage to the

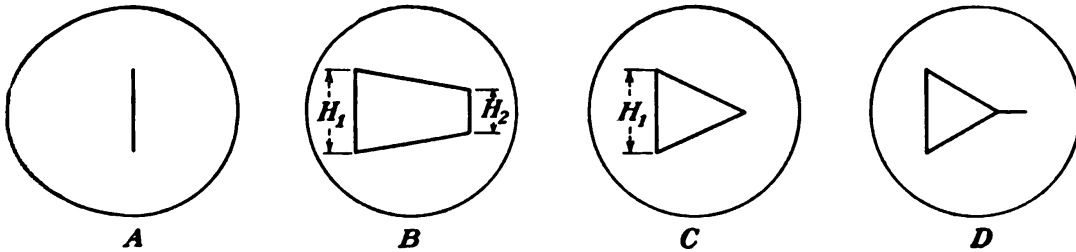


FIG. 5-80.—Trapezoid pattern of modulation.

horizontal deflection plates instead of the "timing" saw tooth. The so-called *trapezoid* patterns result, as illustrated in Fig. 5-80.

In Fig. 5-80, the pattern A results from an unmodulated radio-frequency wave. Pattern B is the trapezoid of partial modulation. The percentage of modulation may be easily determined by the dimensions H_1 and H_2 .

$$\text{Modulation percentage} = \frac{H_1 - H_2}{H_1 + H_2} \times 100 \quad (48)$$

Pattern C is the "trapezoid" of 100 per cent modulation which is the limiting case or an isosceles triangle. Pattern D represents overmodulation.

The first method described has a distinct advantage over the trapezoidal measurement since opportunity is presented to observe the actual audio wave form. Thus, it is possible to observe flattening of peaks as other evidence of distortion which cannot be seen when using the trapezoidal method.

d. Aligning Procedure.—The cathode-ray oscilloscope offers a rapid and an efficient visual method of aligning cascaded overcoupled intermediate-frequency amplifier stages. The oscilloscope's horizontal deflecting plates are connected across the second-detector output, which in most cases will be the diode-detector load resistance. The output of a

signal generator which is frequency modulated (usually designated as a "sweep" generator) is connected to the input of the last intermediate-frequency stage. The frequency sweep is arranged to cover the entire intermediate-frequency band pass. The relaxation oscillator in the "scope," which supplies the linear time axis, is adjusted to a frequency corresponding to the sweeping rate of the signal generator. Most sweep generators provide a "sync" output which is connected to the external "sync" binding post of the cathode-ray oscilloscope to synchronize the generator sweep note with the timing sweep of the oscilloscope. As the generator sweeps through the pass band, the amplitude of voltages imposed on the vertical plates will vary with the response of the circuit at the frequency being instantaneously impressed. As the horizontal sweep is moving the spot across the screen as the frequency changes, the image on the screen will represent a formation of the curve of response against frequency. If the sweep generator sweeps both up through the pass band and then down, there will be two traces on the screen, one a mirror image

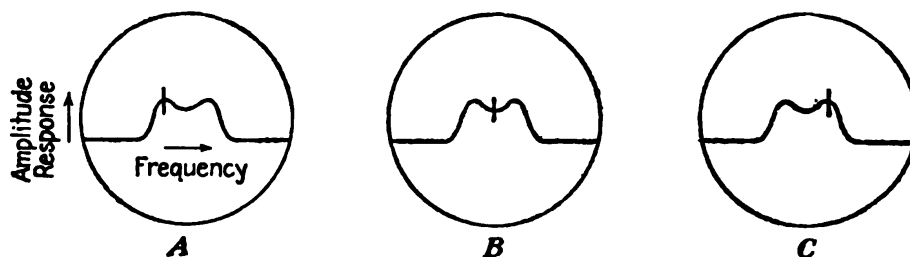


FIG. 5-81.—Aligning trace.

of the other. Many generators employ a blanking method, however, so that the frequency output sweeps only in one direction and the return is "blanked out." In the latter case, only one trace is visible. A marker frequency or steady radio-frequency output, either generated by the sweep generator or an external generator, if set at the center of the band, provides a reference point for adjustment and may be varied back and forth to determine if the pass band is correct. Thus, with the marker and the frequency trace on the cathode-ray screen, it is a simple matter to align the primary and secondary of the intermediate-frequency transformer to secure the required center frequency and pass band. Figure 5-81 illustrates a typical aligning trace of a properly aligned intermediate-frequency transformer. Pattern A shows the marker frequency adjusted for the lower end of the pass band. Pattern B shows the marker set at the center frequency, and at pattern C the marker frequency equals the upper frequency limit.

The preceding stages are then aligned by having the "scope" connected across the second-detector output and applying the generator input to the inputs of the preceding stages one by one, working back toward the converter and aligning each transformer successively for the proper response curve as traced on the cathode-ray screen. When align-

ing the first intermediate-frequency stage, the generator is connected from the converter grid to the ground or chassis. In this last instance, as the preceding radio-frequency transformer, antenna, or loop circuit may offer a very low impedance at the intermediate frequency, it is advisable to disconnect the connection to the grid terminal of the converter socket. The heterodyne oscillator should be made inoperative by removing the oscillator tube from its socket.

A method similar to that used in intermediate-frequency alignment may be applied to the discriminators¹ of frequency-modulation receivers or transmitters. In this case, the signal generator is set to sweep through the intermediate-frequency pass band as before and the familiar S curve of discriminator response is sought.

e. Summary.—The cathode-ray oscilloscope offers the serviceman or radio operator a means of tracing wanted signal and unwanted noise voltages right through a radio receiver or transmitter. Since the oscilloscope has negligible loading effect on the high-impedance circuits involved, it may be used where other devices are difficult or impossible to utilize. It becomes relatively simple, for instance, to determine the effectiveness of power-supply filters, and the amount of fundamental and higher order hum present can be immediately estimated. Defective audio transformers are quickly found, and faulty capacitors, which when open are not indicated in a point-to-point resistance or voltage check, may be instantly picked out.

The screen material of cathode-ray tubes is made to emit light of a variety of colors ranging from pink through blue, white, and green. The persistence of the screen material is its ability to continue to emit light after the exciting electron beam is removed. Screens of various persistences and color characteristics offer a means of adapting the tube to the conditions of use.

For ordinary laboratory or service work, a green medium-persistence screen offers the advantage of easy visibility to average room illumination and little eye strain when used over long periods. The green light is sufficiently active to permit ready photographs of the image with a standard "still" camera. For motion-picture work, a more highly actinic blue screen with a short persistence will avoid blurring and give much better results. When observing low-speed phenomena or non-recurring transient effects, a long-persistence screen material is indicated.

Whenever a cathode-ray tube is permitted to operate with no voltages applied to its deflecting plates, that is with a single spot appearing on the screen, it is desirable that the intensity control be set close to minimum since the high intensity of an electron beam concentrated on a small screen area will soon discolor or burn a portion of the screen material permanently and reduce or destroy its efficiency.

¹ See Chap. 8.

switch is turned to any desired range is easily observed. A change of several milliamperes should be obtained on all points in the low-frequency range; a change of from 0.25 to 1.0 ma. should be obtained on all points in the high-frequency range. When a signal introduced at the coupling post is of sufficient intensity, visual beats are indicated by the detector plate-current meter, if the frequency of the heterodyne is within a few cycles of zero beat with the introduced frequency.

b. Theory of Operation.—The apparatus combines two essential elements, a stable oscillator of adjustable frequency and a detector, in a form convenient for use in frequency measurements. The oscillator is especially arranged for permanence (by rugged construction) and freedom from frequency shifts due to changes in supply voltages (by voltage compensation, described later). The detector is used to produce audible beats between the frequencies of the oscillator and some other oscillator (such as a transmitter or a separate crystal-oscillator calibrator).

The heterodyne oscillator circuit is a modified form of Colpitts oscillator, which is inherently one of the most stable types. The construction of the oscillating circuit is made as rugged as the requirements of size and weight will permit. Voltage compensation is obtained by properly proportioning the plate and screen-grid voltages of the oscillator tube by means of a voltage divider, so that variations in total plate-supply voltages produce very small variations in frequency.

If two alternating voltages, of different frequencies, are impressed on a non-linear grid circuit (that is, a circuit which does not follow Ohm's law) the average grid current will undergo variations at a rate equal to the difference of the two frequencies. If the two frequencies are radio frequencies (above audibility) and the difference between them is made small enough to result in an audio-frequency beat current (within audibility), then the variations in grid bias take place at an audible rate. These variations are amplified by the tube, and, if telephones are connected in the plate circuit, the plate-current variations will produce a tone in the telephones. If the difference between the two frequencies is made very small (only a very few cycles), then the telephones will no longer respond to the difference, or beat, frequency. A meter placed in the plate circuit will indicate by pulsations these very low-frequency current variations, or beats, when necessary.

The compensating condenser, located near the coupling binding post, is provided for adjustment of the initial capacity of the tuned circuit. The condenser is provided with a screw-driver adjustment, access being obtained by means of a removable spring cover. If the heterodyne oscillator has been calibrated and a change in initial circuit capacity takes place, the calibration will of course be in error. Such changes may be in tubes, or due to slight displacement of the parts of the instrument relative to each other or relative to the case. Adjustment of the compensating condenser so that the reading of the instrument agrees with the original calibration will bring all other points into agreement, provided the change in the circuit under measurement was a change in initial capacity. The compensator will not realign the instrument against changes in tube characteristics or changes in coil inductances, though adjustment of the compensator will aid materially in reducing shifts due to other causes than changes in the initial circuit capacity.

c. Practical Operation.—Shortly before the instrument is to be used for adjusting a receiver or a transmitter to a desired frequency, the heterodyne frequency meter must first be checked against a crystal-oscillator calibrator. In checking, it is possible to listen for beats with the telephones connected to either the crystal-oscillator [calibrator] or the heterodyne frequency meter. The coupling between the calibrator

and the frequency meter is obtained by connecting the COUPLING posts on both instruments together. If the coupling is too great, the wires may be left disconnected but close to each other, thereby providing slight electrostatic coupling.

If the crystal calibrator provides a crystal harmonic at a desired calibrating frequency, identify the harmonic by referring to the crystal-oscillator calibration. Then set the crystal-oscillator (calibrator) to zero beat with this harmonic. Turn off the crystal-oscillator (calibrator), and start the heterodyne frequency meter by closing the filament switch.

Select the proper coil of the heterodyne, as determined by reference to the range table on the panel (that is, the coil having a range in which are located the calibration points desired). Turn on the calibrator and adjust the variable condenser C_1 of the heterodyne meter until zero beat with the crystal-oscillator calibrator frequency is obtained. If the width of the zero-beat setting, as determined by headphones, covers several divisions on the condenser dial, a more accurate setting may be obtained by noting the pulsations of the detector plate-current-meter pointer, either side of zero-beat setting. If the signal is too weak to operate the meter needle in this manner, coupling between oscillators should be increased.

The frequency-meter oscillator may now be turned off, and the heterodyne frequency meter slightly readjusted to give zero-beat setting directly against the (calibrator) harmonic.

The frequency, coil, and condenser settings, and the temperature should be entered on the removable calibration card on the panel.

If the crystal calibrator does not provide a crystal harmonic at the desired calibrating frequency, first set the calibrator frequency to the desired frequency by interpolation between harmonics of the crystal, which occur near the desired calibrating frequency. Turn off the crystal oscillator.

Next, start the heterodyne frequency meter, check voltages, and note temperature. Select the proper coil on the CGR-41 heterodyne, as determined by reference to the range table on the panel. Then adjust the variable condenser C_1 until zero beat with the calibrator frequency is obtained.

The frequency, coil, and condenser settings, and the temperature should be entered on the removable calibration card on the panel of the frequency meter.

To Set a Receiver to a Desired Frequency.—Since the radiation from modern oscillating receivers is small, it is best to listen on the receiver. Start up the portable heterodyne frequency meter and adjust it to the checked frequency, making correction in the dial reading for any change in temperature of the instrument. Adjust the receiver to zero beat with the frequency of the frequency meter. Because of the comparatively great sensitivity of a receiver, very loose coupling between the receiver and the heterodyne frequency meter may generally be used. A wire connected to the heterodyne frequency meter COUPLING post and brought near the receiver antenna terminal is generally sufficient. If necessary, the wire (insulated) may be wrapped a few times around the receiver antenna lead to provide larger capacity coupling.

To Adjust a Transmitter to a Desired Frequency.—The headphones must be used with the heterodyne frequency meter for this operation. Start up the frequency meter as previously described, and adjust its setting to the desired checked frequency, making correction in this setting for any change in temperature of the instrument. Adjust the transmitter master-oscillator and antenna circuits, to zero beat with the frequency-meter frequency. (This presumes that the master oscillator and antenna circuit are to be operated on the same frequency without doubling.)

A short piece of insulated wire, connected to the **COUPLING** post of the frequency meter, should suffice for a pickup circuit. In a well-shielded master oscillator, this coupling wire may have to be brought close to the master oscillator circuits, and, of course, all other circuits should be placed out of resonance while calibrating the master oscillator. However, slight readjustments to the master oscillator may be required after all circuits are resonated due to coupling effects between the transmitter circuits. Checking the transmitter output frequency against the calibrator should be the final operation, and the output should be at zero beat on the heterodyne frequency meter when all circuits are finally in resonance. This final measurement of the antenna circuit should be made with very loose coupling to the heterodyne frequency meter, which will require no coupling wire, and with the frequency meter placed at a remote location in the radio room.

V. LOUD-SPEAKERS

5.32. Loud-speakers.—A *loud-speaker* is an electroacoustic device designed to radiate acoustic energy into a room or open air. As such the loud-speaker is the tangible link between the listener's ear and the audio-frequency system and is generally known by the short term *speaker*.

a. General Considerations.—The loud-speaker consists of the following parts: (1) driving motor, (2) diaphragm, and (3) acoustic radiator.

The construction of the driving motor divides the loud-speaker into various classes, the most common of which are (1) magnetic-armature speakers and (2) moving-conductor speakers. Loud-speakers in the first class are commonly known as *magnetic speakers* and those in the second class as *dynamic speakers*. Each of these types is made in various forms of which only the most commonly used are considered here.

b. Magnetic Speaker.—The balanced-armature type of magnetic speaker is shown in Fig. 5-83. The driving motor of this speaker consists of a permanent polarizing magnet, electromagnetic coils, and a magnetic armature.

In the type of speaker shown in the illustration, the diaphragm and the acoustic radiator are combined in the form of a paper cone. This cone is connected to the magnetic armature by a driving pin as shown.

The armature is traversed by a combined field set up by the permanent magnet and the coils. These coils are connected to the output of the audio amplifier. The function of the permanent magnet is to provide an opposing polarity at each end of the armature, thus causing simultaneous attraction and repulsion at each end of the armature when the armature is alternately polarized by the audio-frequency coil currents. Hence, on one alternation the armature is attracted by the pole faces *X, X* and repelled by *Y, Y*. On the next alternation the converse happens, with attraction at *Y, Y* and repulsion at *X, X*. Therefore, for each

audio cycle one complete cycle of vibration of the armature occurs, and fidelity of reproduction is achieved.

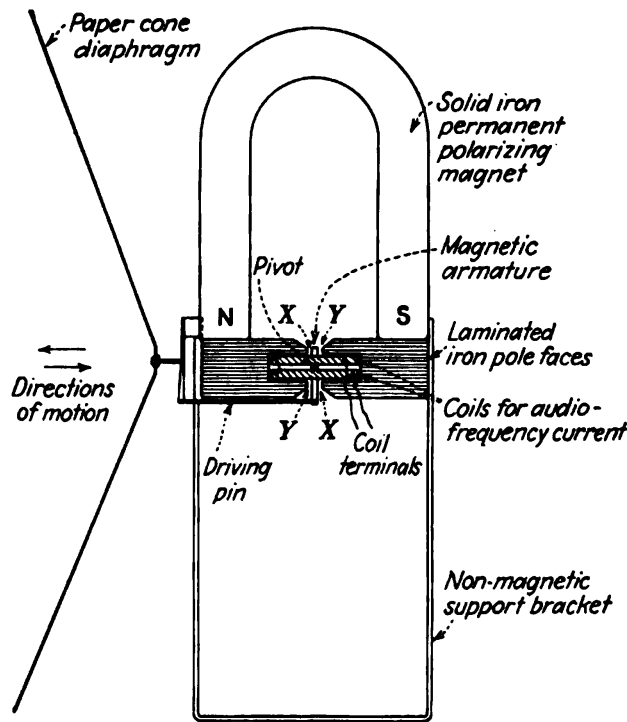


FIG. 5-83.—Magnetic speaker.

Direct current should not be allowed to flow through the coil, for this would permanently polarize the magnetic armature, which is undesirable.

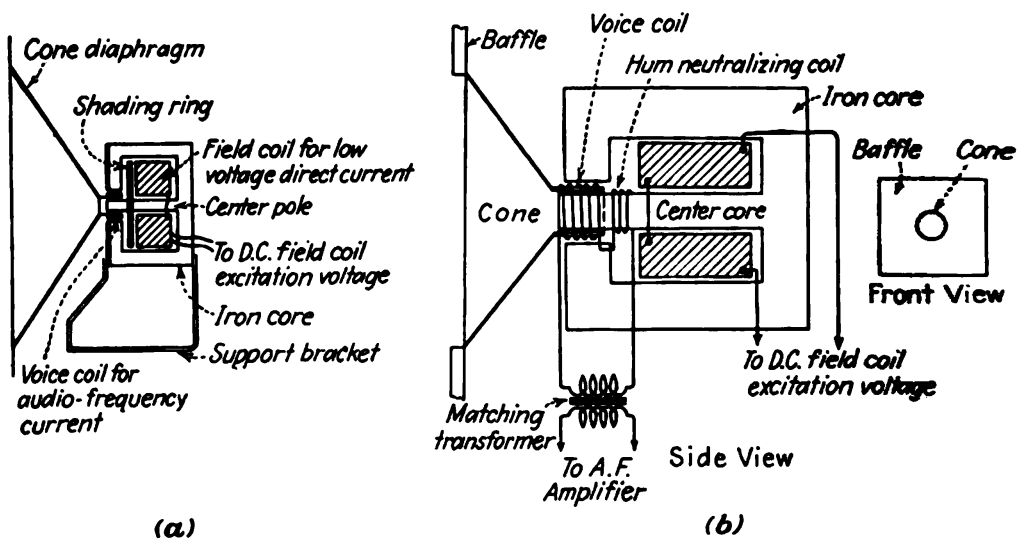


FIG. 5-84.—Dynamic speaker.

c. *Cone Type Dynamic Speaker.*—The commonly used moving-coil energized-field type of dynamic speaker is shown in Fig. 5-84.

The driving motor of this speaker consists of a steady applied field and a movable voice coil, which floats in two small air gaps in the magnetic circuit as shown.

The voice coil is connected to the output of the final audio power amplifier through a matching transformer. A typical coil consists of from 100 to 150 turns of No. 34 silk-covered wire. Its impedance is then in the vicinity of 6 ohms at 100 cycles.

The action of the speaker depends upon the movement of the voice coil along its axis for a fraction of an inch. This movement is caused by the magnetic reaction between the steady applied field and the field set up around the voice coil by the audio-frequency current. During one alternation of the audio-frequency current the voice coil is forced out, and on the following alternation the coil is forced in. Therefore, for each audio cycle one complete cycle of vibration of the coil occurs. The coil is attached to the diaphragm, which in the type shown is of the paper-cone type supported around its outer edge and functioning also as the acoustic radiator. Hence the cone also vibrates and sets up corresponding air waves generating a true acoustic reproduction of the audio-frequency output of the amplifier. The size of commercially available cones varies from 4 to 12 in.

The steady applied field is due to the flux produced by the *field coil*. The energizing voltage may be of any value convenient to the design. Voltages from 6 to 200 volts have been used for excitation. More recently the applied field is supplied by a permanent magnet. This speaker is known by the short term *P-M dynamic speaker*. With this arrangement no field voltage is necessary.

The disadvantage of the energized-field type of speaker is that a low-frequency hum may appear in the output because of the slight ripple in the energizing voltage present when the initial source of energy is the alternating-current power and lighting circuit. To prevent this hum several expedients have been used. The simplest is, of course, to supply the field from a permanent magnet, thus doing away entirely with the hum source. Another method is to utilize a hum-bucking coil, as shown in Fig. 5-84 (b). This coil consists of a few turns of wire wound in the opposite direction, connected in series to the voice coil winding and mounted on the end of the center core. This winding is designed to produce a field of opposite phase to the low hum-voltage, thus canceling the effect of this voltage and the hum. Another method is to use a so-called *shading ring* as shown in diagram (a). This ring consists of a thick copper disk and is permanently fixed to the center pole of the field core. This disk acts as a single-turn coil which has strong eddy currents induced in it. These eddy currents buck the flux movement and tend to keep the field stationary. Thus the relative motion between the voice coil and the field at the hum frequency is reduced and its ability to induce a hum voltage in the voice coil minimized.

The phase of the sound wave on one side of the cone diaphragm is 180 degrees out of phase with that on the other side. Hence if these two waves merge they tend to cancel one another. To prevent this a baffle is employed as shown in the front and side views of Fig. 5-84(b). To be effective the baffle should be as large as possible and should offer a minimum path from the front to the back of the cone of not less than one-half wave length of sound at all audio frequencies. Hence for linear reproduction of the low audio frequencies the baffle should be at least 2 or 3 ft. on a side depending upon the size of the cone.

The advantage of the moving-coil (dynamic) speaker over the magnetic-armature (magnetic) speaker explained before is that the output of the dynamic speaker is flatter over the entire audio range. Also its output is substantially greater on nearly all frequencies. The dynamic speaker, because of the freedom of movement of the voice coil, can reproduce the harmonics of each tone better than the magnetic speaker, giving more timbre to the reproduction and a more lifelike quality to the speaking voice.

d. Horn Type Dynamic Speaker.—For high acoustic output and wider frequency range at practical speaker efficiencies, a horn is necessary as the acoustic radiator. To generate an equal output with a cone and baffle speaker would require much greater audio-amplifier output power. Also the heat generated in the voice coil of the low-efficiency cone speaker would be many times that generated in the horn type speaker with the consequent need for larger units to handle this extra heat.

The driving motor used in the horn type dynamic speaker is similar to the driver used in the cone and baffle type. The principal difference is that in the horn type speaker a separate and smaller diaphragm, not much larger than the throat of the horn, is used. The voice coil is securely fastened to this diaphragm.

The function of the horn is to direct the sound and to place an acoustic load on the diaphragm. When the diaphragm vibrates it causes the column of air in the horn to vibrate along with it, thus generating an intensified sound wave. Without the horn this wave would be feeble, owing to the small diaphragm area in contact with the air. The gain in wave pressure is a function of horn taper. For maximum gain a so-called *exponential horn* is used. This type of horn has a logarithmic taper, which means that the cross-sectional area doubles at equal distances along its length. Obviously such a horn, if built as a straight horn, would have great length. It is possible, however, to fold the exponential horn in a number of different ways and thus take advantage of its high efficiency as an acoustic radiator without cumbersome length.

Horn tapers other than exponential may be and are used at lower efficiencies, particularly in public-address systems. But modern design favors the exponential horn over other types.

CHAPTER 6

ELECTRONIC POWER SUPPLIES

If a high-voltage direct current could be taken directly from the power lines leading to a radio transmitter or receiver, a rectifier and its associated apparatus would be unnecessary. Unfortunately high-voltage direct current is not universally available for the operation of vacuum tubes, and, excepting for low-powered battery-operated and motor-generator-powered installations, rectified alternating current must be used.

Such a conversion of power requires a rectifier, which is a device having an asymmetrical-conduction characteristic, and which is used for the conversion of alternating current into a pulsating direct current. It is the purpose of this chapter to explain the theory and operation of rectifier apparatus as used to supply power to modern radio equipment.

The parts of a rectifier system in the order of their functioning are (a) the power transformer, (b) the rectifier, (c) the filter, and (d) the voltage divider (if used).

I. THE POWER TRANSFORMER

6.1. General Transformer Considerations.—The principles of the transformer have been treated in Sec. 2.2 and will not, therefore, be further discussed here. There are, nevertheless, certain points which apply to a rectifier transformer that need explaining.

a. Heating in a transformer used for rectifier service is more pronounced for a given power than when the same transformer is used as a conventional converter of alternating current. This is due to the rectangular shape of the pulses flowing in the secondary which have a greater heating effect than a pure sine wave. While it is possible to design a transformer which will run cool, it is much more economical, and not disadvantageous, to allow it to run warm. The heat, of course, must never be allowed to rise to the point where the insulation of the transformer would be damaged. Very high-power transformers are usually oil cooled. When oil cooling is unnecessary, air cooling is used on all types, the cases being corrugated to provide a greater heat-radiating surface.

b. Direct-current Saturation.—If an alternating current is passed through a transformer winding, the flux will change position with each alternation. Likewise, if an iron core has two coils on it, with the current

in the coils flowing in opposite directions and the current flow taking place in each coil alternately, a similar action of flux reversal will take place owing to the reversing magnetic effect of the coils. On the other hand, if pulses of direct current are caused to flow through a transformer winding, the first few pulses will function to arrange the flux in the magnetic path in a certain direction, and the succeeding pulses will have less and less work to do in this respect because there is no reversing force to undo the work of each pulse. This condition may exist in a rectifier transformer.

As a transformer depends for its operation on the number of lines of force or flux which ebb and flow around the magnetic path, any reduction in this flux movement will reduce the effect of the transformer. It is apparent, therefore, that, if current pulses flow through a transformer winding in one direction only, direct-current saturation will take place eventually. In other words, if direct-current pulses are caused to flow in a transformer winding, eventually the flux in the magnetic path of the transformer will become more or less fixed in one position, and the pulsating current will have but little effect in causing the flux to move. This condition is called *direct-current saturation*.

Direct-current saturation is considered a loss and is likely to take place to a greater or less degree in any transformer winding in which the current pulses flow always in the same direction. Such a condition of current flow takes place in the single-phase half-wave rectifier circuit (Fig. 6-4), and in the three-phase half-wave rectifiers with star-connected secondaries (Fig. 6-14).

To prevent direct-current saturation, the magnetic path of a transformer or choke coil may be interrupted by an air gap of a few hundredths of an inch. This is necessary in transformers only when they are used in circuits where there is a possibility of direct-current saturation. As there is always the possibility of such saturation in a ripple-filter choke (Sec. 6.20), owing to the direct current flowing through it, these chokes are usually designed with an air gap in the magnetic path of the core material to stabilize the inductance value within a given range.

Another method of preventing direct-current saturation in high-power rectifier transformers is to wind the secondary in sections or pies and then interlace the sections; that is, every other section is connected in series to form one side of the center tap.

c. *The number of windings* and the particular construction of each depend on the service to which the transformer is to be put. A straight power transformer for use in stepping up or stepping down the voltage may require but a single primary and a single secondary circuit. Such a transformer could be used in a half-wave rectifier as in Fig. 6-4. Usually, if the transformer is to be used in a full-wave rectifier circuit, the secondary must be center-tapped as is T_1 , Fig. 6-5.

In low-power rectifiers, such as are used in receivers, it is the usual practice to combine the plate and filament transformers into one unit. One or more filament windings may be necessary depending on requirements. It may be necessary to provide a separate winding for the radio-frequency tubes, another for the audio-frequency tubes, and still another for the rectifier filaments. All of these secondary windings operate from a single primary winding.

In high-power rectifiers intended for use with transmitters, and where a considerably higher voltage is used on the plate circuits, it is necessary to operate the filaments from a separate transformer, as can be verified by studying some of the transmitter diagrams given in this book. It is important that each winding be able to carry the load imposed on it in the particular circuit in which it is used. In choosing or designing a rectifier transformer all of these points must be considered.

d. Rating of Transformers.—The rating data of a power transformer are contained on its name plate and usually specify the input voltage and

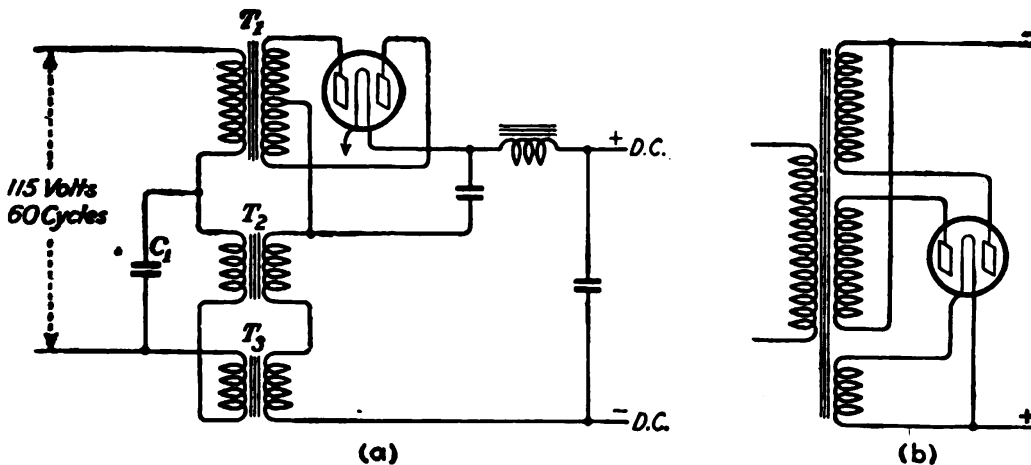


FIG. 6-1.—(a) Voltage-regulating transformer circuit; (b) reversed-winding method of shielding.

frequency, and the output volts, current, and power. It is common practice to rate general power transformers as to their safe output in kilovolt-amperes. The reason for this is explained in connection with the section on Kilovolt-amperes (see Sec. 2.29).

6.2. Voltage-regulating Transformers.—The theory of operation of the voltage-regulating transformer centers around the principle of the reduction of impedance in a reactor when its core is saturated. A schematic circuit diagram of the scheme employed is shown in Fig. 6-1(a). In this particular transformer there are two small transformers T_2 and T_3 which supply the regulation properties of the unit. As shown in the diagram these two small transformers have the secondary winding of each placed in series with the negative return of the rectifier circuit. Their two primary windings are placed in series with the primary of the high-voltage transformer.

In the ordinary high-voltage transformer not supplied with regulating windings the voltage delivered by the secondary will tend to drop in value as the current drawn by the load is increased. In the voltage-

regulating transformer circuit here shown a complex action takes place which maintains the voltage delivered by the secondary at a steady value regardless of the load within certain limits. This regulating action may be explained as follows: When the current drawn by the load is increased, the flux in the cores of regulating transformers T_2 and T_3 is increased toward saturation; this reduces the reactance of the primary windings of these transformers permitting a higher voltage to be applied to the primary of the high-voltage transformer, thereby maintaining the value of the secondary output voltage of this transformer constant.

It is necessary to use the two secondary windings of T_2 and T_3 in opposition, and they must be very closely balanced owing to the fact that the alternating current across the primaries produces an alternating current in the two secondaries which are in series with the direct-current supply portion of the rectifier, and if they do not buck out, a marked ripple is applied to direct-current output.

The condenser C_1 is placed across the two units for the purpose of shifting the phase relations, and by proper selection of the capacity of this condenser the regulation of the transformer can be varied.

6.3. Electrostatically Shielded Transformers.—The function of the electrostatic shield which is usually placed between the secondaries and the primary of some high-grade radio transformers is to prevent the transfer of any high-frequency disturbances in the power line from reaching the tube circuits connected to the secondary and also to prevent any high-frequency disturbances in the tube circuits from being transferred back to the line. This shielding is grounded to the transformer casing which in turn is connected to the ground, thus effectively by-passing all electrostatic e.m.fs. passing between these two circuits to the ground. Therefore, the electrostatic shield in a transformer tends to reduce key-click surges, tunable hums, and to keep radio-frequency currents from entering the power circuits.

It is also possible to secure some shielding action in power transformers used with radio receivers by winding one of the filament windings having a grounded center tap between the primary and secondary windings.

Another means of shielding is to place the outside windings of the secondary at ground potential by means of the *reversed-winding* method in which the two halves of the high-voltage winding have their *outside* terminals connected to the ground instead of to the plates of the rectifier which is the usual procedure. The two *inside* connections are connected to the rectifier plates as illustrated in the diagram, Fig. 6-1(b).

6.4. Protective Devices.—It is considered good practice to place fuses in the primary circuit of a power transformer to protect it against excessive overloads. These fuses are generally rated about 50 per cent in excess of the normal load current.

Surge gaps and arcing horns are sometimes fitted to the transformer secondary of high-power line transformers to provide a path for high overload currents which might otherwise break down the secondary insulation.

II. THE RECTIFIER

6.5. The Function of the Rectifier.—As its name implies, the purpose of the rectifier is to rectify alternating current into direct current, pulsating in character but nevertheless flowing in only one direction. A rectifier functions in this way because of its ability to allow current to flow more easily in one direction than in the other.

Although there are many types of rectifying devices operating on mechanical, electrolytic, thermal, and thermionic or electronic principles, the radio operator or engineer is mostly concerned with the so-called *thermionic-type* rectifier utilizing vacuum tubes as the rectifying element. It is to this type, therefore, that the discussion here will be principally, but not entirely, confined.

The theoretical operation of the two-element tube as a rectifier is as follows:

A fundamental rectifier circuit is shown in Fig. 6-4. As soon as the filament F is heated and emits electrons, these electrons are drawn over to the plate P when the plate is positive with respect to the filament, resulting in a current flow through the circuit. If this current path is traced out, it is seen that, starting at the lower end of the transformer secondary, the current flows to the lower terminal of the output, through the load to the upper terminal of the output, thence to the filament and across to the plate by electronic conduction back to the upper end of the transformer completing the circuit.

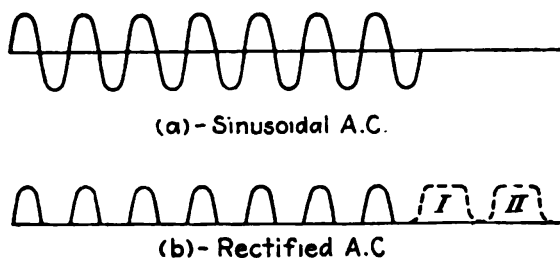


FIG. 6-2.—Effect of half-wave rectifier on alternating current.

It is important that we get polarity relations straight in our minds at this point. We know that polarity is a measure of potential between two points and that current flows from negative to positive. Therefore, if we make an instantaneous observation of polarity during the half of the alternating-current cycle when the rectifier tube is passing current, we would find (a) that the plate is positive with respect to the filament, (b) the upper end of the transformer is positive with respect to the lower end, and (c) the upper output terminal of the output is positive with respect to the lower terminal. Considering the output, it is now clear why the positive terminal of the rectifier is taken from the filament or cathode of the rectifier and not from the plate. This becomes clear from studying the diagram.

On the next alternation of alternating current the potential in the secondary of the transformer is reversed, and the plate of the tube becomes negative with respect to the

filament. Under these conditions the tube does not conduct current, instead it (the tube) takes the form of an infinite resistance. Thus only those alternations flowing in the direction in which the tube conducts are allowed to pass, and pulsating direct current results.

A graph showing the effect of the rectifier on the alternating current is shown in Fig. 6-2(b). The alternating current entering the transformer is shown as a sinusoidal wave form (a); the rectified direct current delivered to the output is shown as a pulsating wave form (b). This is the wave form at the output before the filter is applied (disregard the pulses marked I and II for the present; they will be referred to in Sec. 6.7).

6.6. The high-vacuum rectifier tube is a two-element tube, essentially the conventional three-element vacuum tube in construction with the grid omitted. Into this tube a high vacuum is introduced, and all possible traces of gas are removed to prevent the tube from breaking down under high-potential strains.

The two most important characteristics in connection with this rectifier are: (a) maximum peak plate current, and (b) maximum peak inverse voltage.

The maximum peak plate current is the safe value of peak current that the tube can handle under continuous operating conditions. Normally it is governed by the cathode emission permissible with a given tube. As the direct current flows in a rectifier tube for only half the time the tube is in operation, this current as indicated by the plate milliammeter should never be allowed to exceed more than half the maximum peak plate-current rating of the tube.

The maximum peak inverse voltage is the maximum potential applied across the tube while it is non-conducting. In other words, it is the maximum voltage across the tube during the alternation the tube is idle. For example, in Fig. 6-2 the tube is idle during each negative alternation (below the line) of sinusoidal alternating current; hence no rectified alternating-current pulses result during these periods. As the study of rectifier circuits is made, it will become clear that this maximum peak inverse voltage is practically the peak voltage of the transformer secondary in single-phase circuits.

An important factor in connection with the high-vacuum tube is the voltage drop across the tube during operation. When the cathode is heated, electrons are drawn toward the plate and a space-charge voltage drop is built up in the tube, which depends upon the current drawn and the construction of the tube (see Sec. 3.1). This voltage drop may vary from a few volts to several thousand volts. Any circuit calculations involving this tube must take this variable drop into consideration. Furthermore, the regulation in a circuit using this tube is relatively poor and is governed largely by the drop in the tube.

The high-vacuum rectifier tube utilizes a tungsten filament and requires a relatively high filament power. A few types of high-vacuum

rectifier tubes utilizing an oxide-covered filament have been developed for low-power use, the most common of these being the half-wave type RCA-81 and the full-wave type RCA-80.

In high-power rectifiers of the high-vacuum type, it is necessary to dissipate the heat generated in the tube by a water-cooling system which increases the cost and the space required.

The characteristics of various sizes of high-vacuum rectifier tubes are given in the various manufacturer's tube manuals.

6.7. The Mercury-vapor Rectifier Tube. *a. Description.*—One of the greatest American contributions to modern radio power-supply development has been the perfection of the low-pressure mercury-vapor rectifier tube. In order to understand better the reason for this, some of the disadvantages of the high-vacuum type of rectifier tube will be stated, and the way the mercury-vapor tube has eliminated these disadvantages will be pointed out.

One of the chief obstacles to the efficient use of the high-vacuum-type tube is the variable-drop characteristic which causes the regulation of the tube to be very poor. This is an especial handicap in circuits where the load varies over a wide range as in class B amplifiers. The high tube drop also generates heat which must be dissipated in the larger size tubes by a water-cooling system. The filaments, being made of tungsten, require a large power.

The mercury-vapor tube has solved many of these difficulties. This tube under normal operating conditions has a constant tube drop of 15 volts, regardless of load conditions. Because of this low tube drop there is no excessive heating of the tube, and even the large models of the mercury-vapor tubes are air-cooled. At the same time, and for the same reason, the efficiency of the mercury-vapor tube is very much higher. In one comparison made, the efficiency of the high-vacuum-type tube rectifier was 87.5 per cent, while that of the mercury-vapor tube rectifier was 98.8 per cent.

The cost of the mercury-vapor installation is also much less than the cost of a high-vacuum-type tube installation, partly because the water-cooling system is not necessary on high powers.

The two most important characteristics of the mercury-vapor tube are:

1. The maximum peak inverse voltage at which the tube can be operated without flashing back.
2. The maximum peak plate current at which the tube can be operated without filament disintegration.

Since the voltage drop in the tube is only 15 volts it can be neglected, and the inverse voltage is practically the full potential of the transformer secondary in a single-phase circuit. The peak plate current depends on the circuit conditions. In a single-phase circuit the peak current, when the rectifier is connected to a resistance load, is simply the maximum

of the sine wave of the rectified pulses. If inductance is placed in series with the load, the output-current curve takes the form of successive square blocks, as shown by the pulses I and II of curves *b* in Fig. 6-2 and

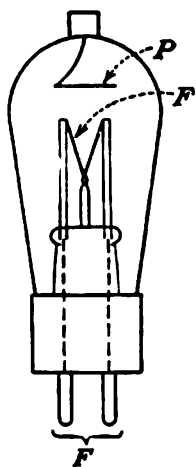


FIG. 6-3.—Mercury-vapor rectifier tube, low-power type.

the peak plate current is nearly equal to the output current. If a condenser is connected across the rectifier output, the peak plate current may reach values equal to from three to five times the output current, and for this reason a condenser is rarely connected across the output of a mercury-vapor rectifier tube, which is sometimes designated by a black arrow head opposite the tube symbol on the diagram.

b. Theoretical Operation.—In the high-vacuum-type rectifier tube the electrons which are emitted by the cathode must overcome a space charge, which surrounds the cathode like a shield, before they can reach the plate [see Fig. 3-2(a)]. This space charge is the cause of the large voltage drop between the elements and is the principal disadvantage of the high-vacuum-type tube. In the mercury-vapor tube, mercury-vapor gas at low pressure is introduced into the tube. The presence of this gas changes entirely the theoretical operation of the tube. A view of the construction of a low-power tube (type RCA-866) is shown in Fig. 6-3. The filament- and plate-voltage supply connections are shown in Fig. 6-4. The elements are placed so as to reduce the possibility of flashover, the plate being located at the top of the tube with its connection being made to a cap.

When the filament of the tube is lighted, the mercury vapor is raised to operating temperature. The high-voltage plate circuit may now be closed and the tube will operate. When the electrons are emitted by the filament and are drawn toward the plate, they collide with atoms of mercury vapor. The collision of an electron with an atom of mercury vapor knocks one of the atom's electrons outside of the influence of its nucleus, and the atom, being minus an electron, becomes a positive ion. This positive ion is immediately drawn over to the space charge surrounding the filament and neutralizes a negative ion in the space charge. In the normal operation of the mercury-vapor tube there are enough positive ions released from the mercury vapor practically to neutralize the negative space charge surrounding the filament. In fact it reduces the space-charge drop to 15 volts, and it remains at this value, regardless of load, during the normal operation of the tubes.

From a practical standpoint the 15-volt drop holds as true for the largest size tube as for the smallest. This means that the voltage regulation of the rectifier unit depends only on the regulation of the transformer, supply, and circuit.

As long as a positive potential is applied to the plate, current will flow through the tube from filament to plate. Therefore, if an alternating potential is applied to the tube, rectification will result. When the plate is negatively charged, it repels what free electrons are in the vicinity as the filament is now positive and the space charge neutralized; and as the cold plate does not emit electrons there can be no ionization of the mercury vapor owing to collision and no flow of current through the tube.

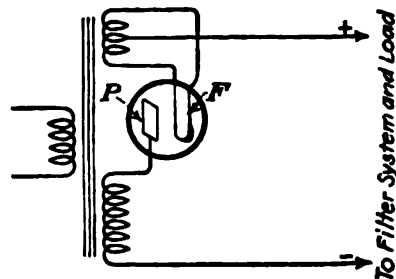


FIG. 6-4.—Single-phase half-wave rectifier.

c. *Practical Operation.*—Great care must be taken not to apply the positive potential to the plate before the filament has warmed up sufficiently to build up a space charge, as ions attracted to the filament under these conditions might strike the filament with such a velocity as to dislodge active material from the filament and possibly ruin the filament entirely. For this reason rectifier circuits employing the mercury-vapor tube are fitted with a time-delay relay which delays the application of the plate potential until the filament has had time to reach incandescence and the proper space charge is formed.

The mercury-vapor rectifier tube cannot be substituted for the high-vacuum-type tube unless the rectifier apparatus, filters, and associated equipment are capable of withstanding the higher output voltage resulting from the lower tube drop. For example, if the terminal voltage at the transformer terminals is 700 volts and the tube drop when using a high-vacuum-type tube is 50 volts, under certain load conditions, the output of the rectifier will be 650 volts. Now, if a mercury-vapor tube with a drop of only 15 volts is used, the output of the rectifier will be 685 volts. The equipment must be able to withstand this higher potential if a substitution of tubes is to be made.

As the filament of the tube is called on to emit electrons to the full extent of the plate current, the filament or cathode must be ruggedly made. In the mercury-vapor tube the filament is coated with oxides of barium and strontium, and it is the evaporation of this oxide coating that determines the life of the tube. High-power tubes are given a heavier coating of oxide than are the tubes designed for lighter loads. If the tube is abused by application of the plate potential before the filament has been brought to operating temperature, the heavy ionic bombardment of the filament which takes place under these circumstances may ruin the filament in a very short time by disintegrating its oxide coating quickly.

6.8. Inverse-peak Voltage.—An examination of the full-wave rectifier circuit shown in Fig. 6-5 will show that when tube 1 is conducting, the

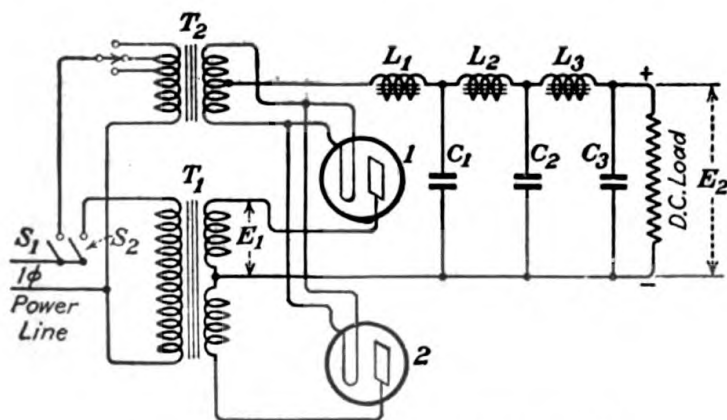


FIG. 6-5.—Single-phase full-wave rectifier.

ull secondary voltage, minus the drop in tube 1, is applied to tube 2. As this is during the non-conducting alternation as far as tube 2 is concerned, it is the inverse of the alternation during which the tube operates as a conductor of current. For this reason it is called the *inverse-peak voltage* applied to the tube to differentiate it from the voltage applied when the tube operates to pass current.

Every rectifier tube has a rating as to the safe inverse-peak voltage at which the tube may be operated. If the maximum peak inverse voltage of a high-vacuum rectifier tube is exceeded, the plate of the tube will get unduly red but no permanent damage will result. If, on the other hand, the maximum peak inverse voltage of a mercury-vapor tube is exceeded, the potential difference between the plate and the filament will exceed the safe limit (usually about 22 volts) and disintegration of the filament will occur, permanently damaging the tube. It is evident, therefore, that, when the mercury-vapor tube is used, great care must be taken in designing the circuit so that the safe inverse voltage will not be exceeded.

Let us return again to a consideration of the circuit. If the mercury-vapor type of tube is used, the drop in the tube is 15 volts. Hence, if, for example, the peak output of the transformer secondary is 5,000 volts, the inverse-peak voltage applied across the non-conducting tube is 4,985 volts, or very nearly the full secondary voltage. Let us now assume a high-vacuum rectifier is used instead of the mercury-vapor tube. The high-vacuum tube may have a drop of from only a few volts to several thousand volts depending on the load conditions. For example, let us say the tube has a drop of 100 volts in the circuit shown in Fig. 6-5. If the transformer secondary yields 5,000 volts the maximum peak inverse voltage across the non-conducting tube is 4,900 volts, the 100 volts being lost in the tube passing the current.

Notice further that the inverse voltage applied to the non-conducting tube is the *full* secondary voltage. In other words, if the voltage each side of the center tap is 2,500 volts, then the *full* voltage is 5,000 volts. This will become clear from a study of the diagram. Notice that the plate of tube 1, for example, is connected to one end of the transformer secondary. Now when tube 2 is conducting, the filament side of tube 1 is connected to the other side of the transformer secondary (the lower end in the diagram, Fig. 6-5) through tube 2 which is now almost as good a conductor as a closed switch, its drop being only 15 volts. Also, if the full voltage of the secondary is 5,000 volts, the secondary of the filament transformer must be insulated to withstand this potential strain as it is the positive side of the rectifier output and is above ground potential.

6.9. Rectifier Circuits Classified.—Rectifier circuits are divided into several classes, namely:

- | | | |
|--------------|---|--------------------------------|
| Single-phase | { | (a) Half-wave circuits. |
| | | (b) Full-wave circuits. |
| | | (c) Bridge circuits. |
| | | (d) Voltage-doubling circuits. |

In addition to these single-phase circuits the following three-phase circuits are in use:

- Three-phase $\left\{ \begin{array}{l} (a) \text{ Half wave.} \\ (b) \text{ Half-wave double Y.} \\ (c) \text{ Full wave.} \end{array} \right.$

6.10. Single-phase Rectifier Circuits.—The operation of the single-phase half-wave rectifier has already been described in connection with Fig. 6-4 which shows the complete half-wave circuit including the filament connections. As the filament of the tube becomes the positive side of the rectifier output, it is essential that the filament-transformer secondary be insulated to withstand the full peak voltage of the rectifier.

A *full-wave single-phase circuit* is shown in Fig. 6-5. As soon as the filaments of both tubes are heated by the filament winding, an electronic emission from both filaments results. However, during the period that the top side of the secondary winding is positive, the bottom side will be negative. Hence, during this period, electrons are only attracted by the plate of the top tube, and a current flows through tube 1 from filament

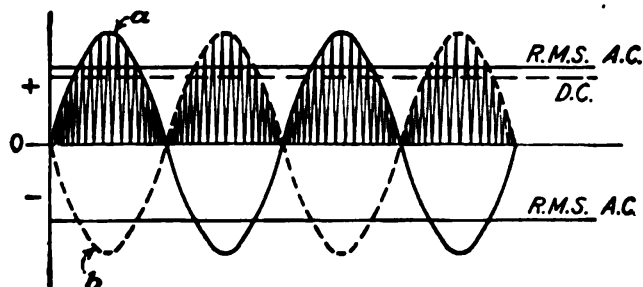


FIG. 6-6.—Effect of full-wave rectifier on alternating current.

to plate. Tube 2 is idle. Then, as soon as the alternating-current e.m.f. reverses its polarity, the lower end of the high-potential transformer becomes positive (+) and the top end negative (-). The current then flows through tube 2, and tube 1 is idle.

Thus, if we consider the polarity of the secondary winding as constantly reversing at a definite frequency, the two rectifier tubes function alternately; that is, when one tube receives a positive potential on the plate, the other tube is negative on the plate, and, as the polarity changes, the condition is reversed. Hence, the current flowing through the load is practically a constant direct current at the filter output. (The function of the filter is explained later.)

In the half-wave rectifier system it will be recalled that the rectified wave shape was of an intermittent character [see Fig. 6-2(b)], that is, the peaks did not follow in rapid succession. However, in the full-wave system the peaks are actually doubled, due to the filling-in action of the second tube. This may readily be seen by referring to the wave shape of a full-wave rectifier system illustrated in Fig. 6-6.

In this set of curves (Fig. 6-6), the potential on tubes 1 and 2 is represented by the sine curves *a* and *b*, respectively. The r.m.s. second-

ary voltage applied to each tube is represented by the lines *R.M.S.* This is the alternating-current voltage indicated by a meter across each half of the secondary, reading from the zero line in the curve diagram in each

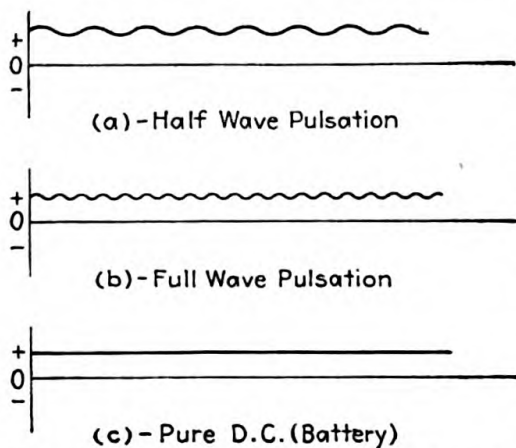


FIG. 6-7.—Comparison of rectified and battery e.m.fs.

instance. The shaded portion represents the rectified pulses of output direct current, available as output voltage. The dotted line *D.C.* is the output voltage of the rectifier. This is the value indicated by a direct-current voltmeter across the output and is 85 per cent of the r.m.s. value of secondary voltage delivered to the tube in this circuit.

Figure 6-7 illustrates the mean current effect in a circuit using either pure direct-current, half-wave, or full-wave rectification. Here it

System (a) produces a rather heavy current fluctuation.

System (b) produces a considerably lower degree of current fluctuation.

System (c) produces practically no current variation as long as the plate-supply batteries are in good condition.

From these illustrations it will be seen that the current fluctuations' even with the full-wave rectifier, are still too great to insure satisfactory

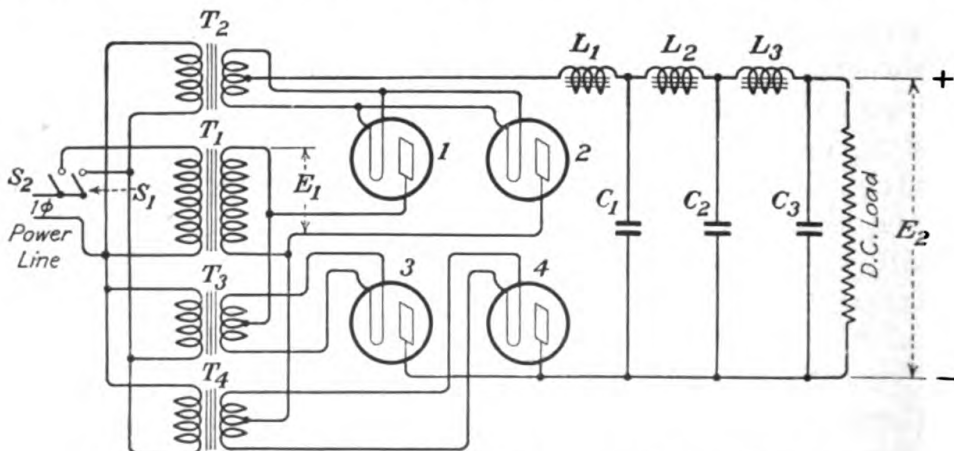


FIG. 6-8.—Four-tube single-phase full-wave rectifier, bridge type.

operation when used as a plate supply for vacuum-tube receivers. It will, therefore, be necessary to smooth the variations or ripples to a still greater degree. This is accomplished by the use of a filtering system consisting of inductances and capacities later to be described (Sec. 6.16).

6.11. Bridge-rectifier Circuit.—The bridge circuit is shown in Fig. 6-8. It is seen that this is a single-phase full-wave rectifier which requires four tubes. A simplification of this circuit is shown in Fig. 6-9. Referring to either figure, the path of the current during one alternation is through tube 4, the load, tube 1 to the other side of the line. During the next alternation the current flows through tube 3, the load, tube 2 to the other side of the line. This circuit is used when a high-output potential is required because the strain is equally divided between the two tubes passing the current; the inverse voltage is likewise equally divided between two tubes materially reducing the strain on each.

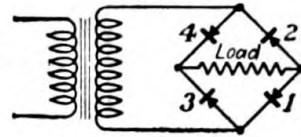


FIG. 6-9.—Equivalent circuit of bridge-type rectifier.

Compared with the two-tube full-wave rectifier, this four-tube circuit utilizes the complete secondary voltage during the whole of each cycle and, therefore, gives twice the output voltage available from the same transformer when only two tubes are used, each utilizing one-half the transformer secondary through the center tap.

6.12. Voltage-doubler Rectifier.—The two-tube half-wave voltage-doubler rectifier is shown in Fig. 6-10 and is similar in some respects to

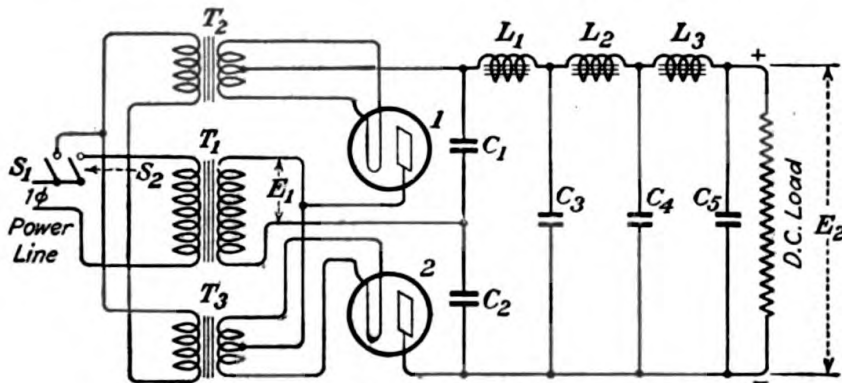


FIG. 6-10.—Two-tube half-wave voltage-doubler rectifier.

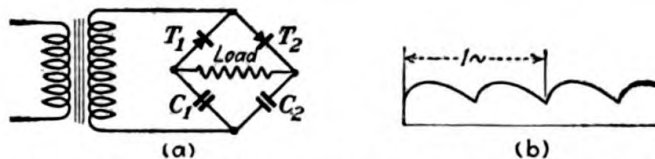


FIG. 6-11.—Equivalent-circuit voltage-doubler rectifier.

the bridge circuit, as will be seen by referring to the diagrams shown in Fig. 6-11(a). Here it is seen that two condensers C_1 and C_2 replace the tubes used in the conventional bridge circuit. A study of this circuit will show that these condensers are charged alternately, first one and then the other, and are discharged in series thereby doubling the output voltage. The output voltage depends entirely upon the size of condensers

used and the current drawn by the load.¹ The maximum current drawn should not exceed the rated capacity of one tube.

A voltage-doubler circuit using four tubes is shown in Fig. 6-12. The total voltage rating in this circuit is twice the rating of a single tube. A graph of the output-voltage wave form of the voltage-doubler circuit is shown in Fig. 6-11(b).

This circuit is useful where an inexpensive rectifier is desired to produce high-voltage, low-current outputs. It may be used with either high-

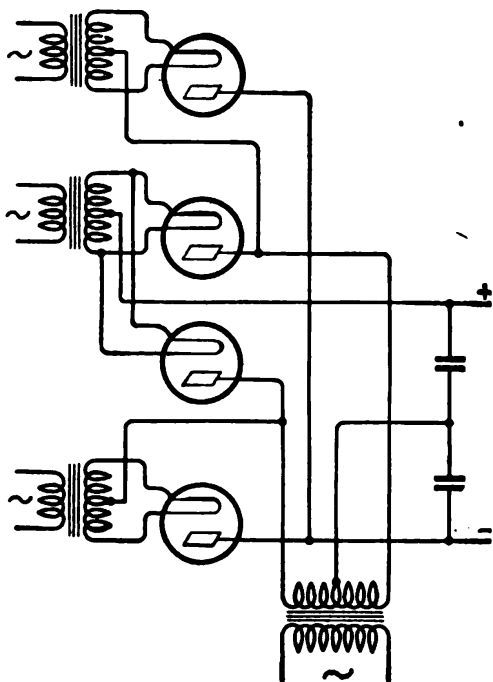


FIG. 6-12.—Four-tube full-wave voltage-doubler rectifier.

vacuum-type tubes or with mercury-vapor tubes. If it is used with mercury-vapor tubes, care must be taken that the inverse-peak voltage does not exceed the safe limit of the tube.

6.13. Three-phase Rectifiers. a.

Introduction.—In Sec. 2.30 on Polyphase Alternating-current Circuits it was pointed out that there are two methods of connecting apparatus to a three-phase circuit. These are the delta and star methods, the latter being also known as the Y, or wye, connection. It is suggested that Sec. 2.30 be reviewed now in order to bring out clearly the voltage and current relations in both the delta and star connections. *The reason for the factor 1.73 in the computation of current and voltage relations in a three-phase circuit*

must be clearly understood. This method of computation applies also to three-phase transformer circuits.

There are four basic methods of connecting three-phase transformers, as shown in Fig. 6-13. The effect of these systems on the value of the rectified voltage is as follows: The *delta-delta* and the *star-star* connections give only the step-up effect of the transformers and may be expressed $E_s = E_p \times T_r$, where E_s is the secondary voltage, E_p is the primary or line voltage, and T_r is the voltage transformation ratio of the transformer.

In the *star-delta* connection the output voltage is expressed

$$E_s = \frac{E_p \times T_r}{1.73} \quad (1)$$

The reason for this is easily seen; the primary of the transformer is star connected which means that the line voltage is not connected directly

¹ For method of calculation of voltage-doubling circuit see Armstrong, Polyphase Rectification Special Connections, *Proc. I.R.E.*, January, 1931, p. 93.

across any single primary winding but is rather applied to two windings in series. This decreases the voltage in each phase winding to the value of the line voltage divided by 1.73. The secondary winding, being delta connected, delivers the full secondary voltage to each phase line. There-

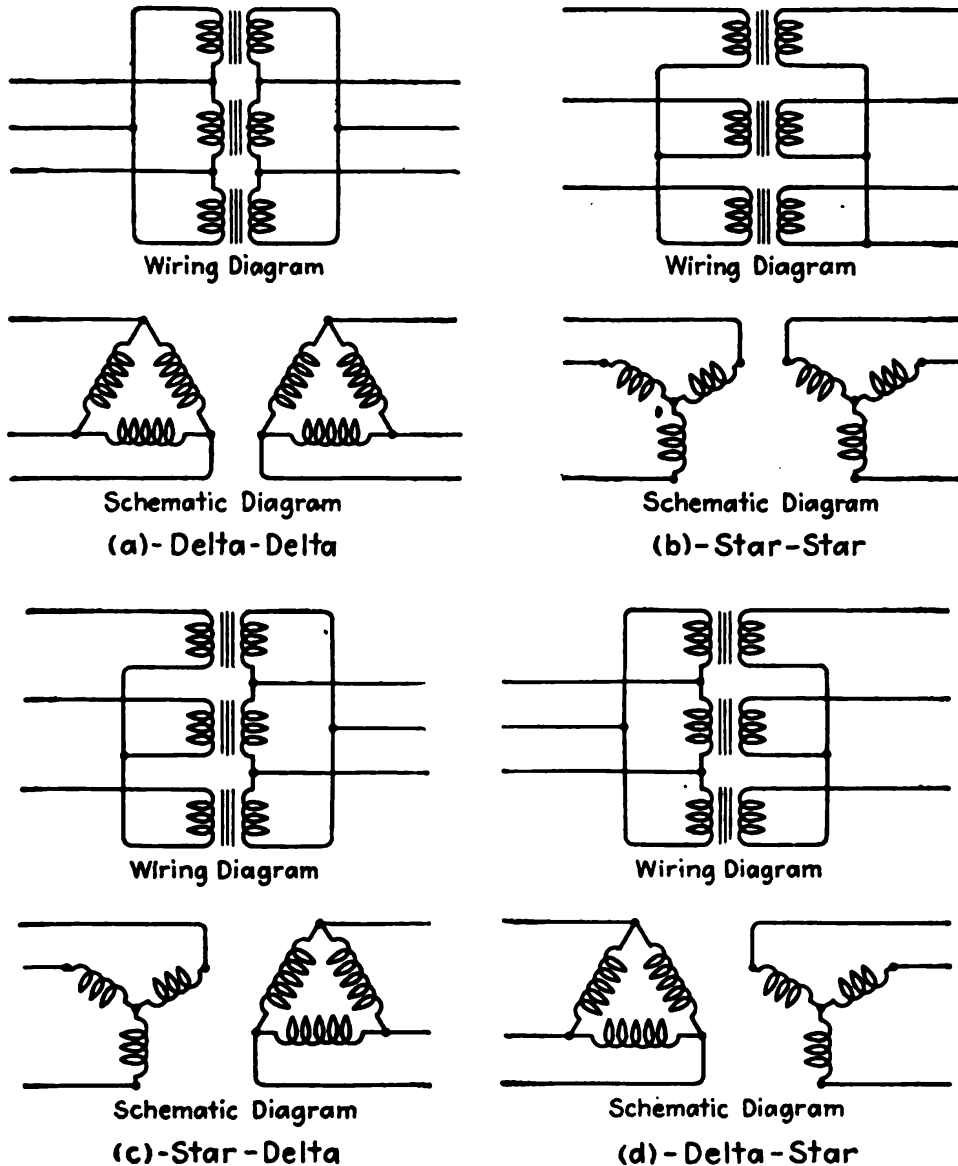


FIG. 6-13.—Transformer connection methods.

fore, it is seen that the output voltage is only $1/1.73$ of the voltage obtained with either the delta-delta or the star-star connection.

In the *delta-star* connection the output voltage is expressed

$$E_s = E_p \times T_r \times 1.73 \quad (2)$$

Here we have the opposite effect to that produced by the star-delta connection. The voltage across each primary winding is the full line voltage, but the secondary line voltage is 1.73 times the phase voltage,

improvement over the half-wave circuits shown before. Here again the delta-star method of connection is employed to get maximum voltage

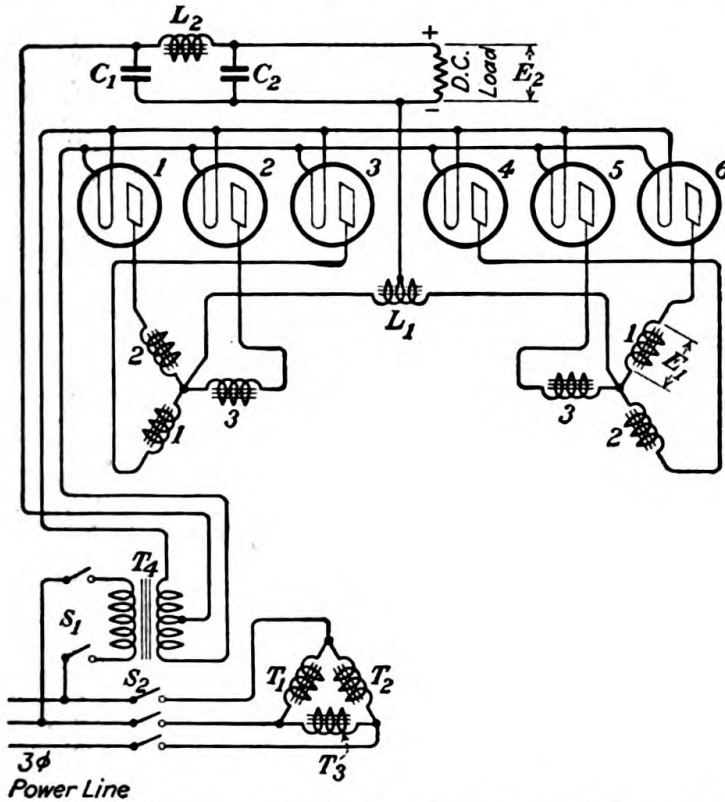


FIG. 6-15.—Three-phase half-wave double-Y rectifier (equivalent to six-phase output).

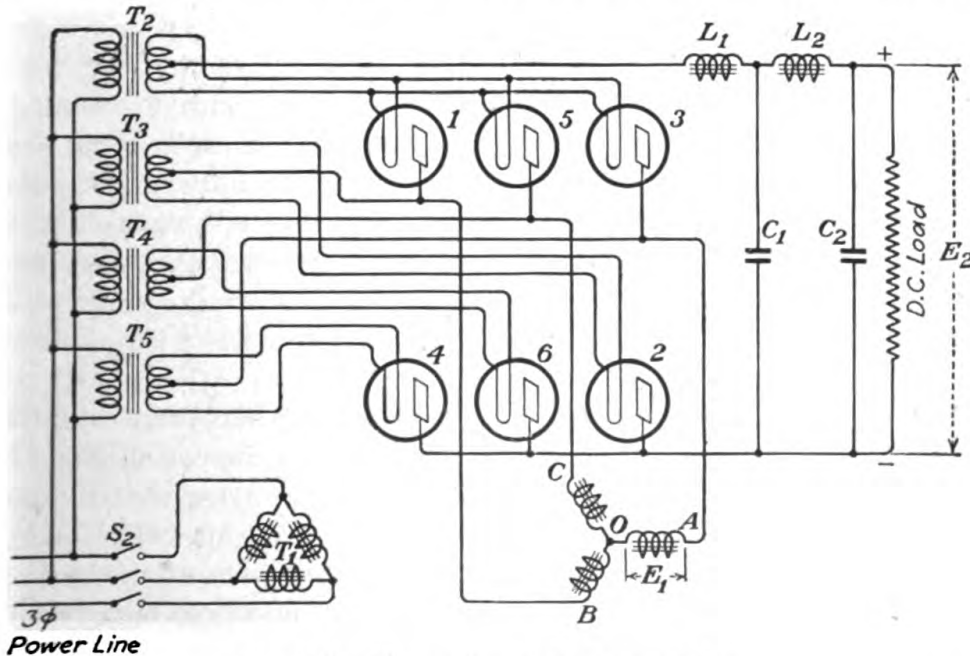


FIG. 6-16.—Three-phase full-wave rectifier.

increase. This circuit is so efficient that the total effect of the rectifier is to more than double the voltage over and above the step-up effect of the

transformers. This circuit is in effect a voltage doubler. This may be explained as follows. Owing to the efficiency of the three-phase, full-wave circuit, $95\frac{1}{2}$ per cent of the transformer secondary-voltage peaks¹ is available in the output of the rectifier. Also, as the delta-star system of transformer connection is employed, the voltage output is again increased by the factor 1.73. Therefore, the output voltage of the rectifier may be calculated

$$E_s = E_p \times T_r \times 0.955 \times 1.4 \times 1.73$$

or

$$E_s = E_p \times T_r \times 2.31 \quad (3)$$

which gives the rectifier more than a voltage-doubling characteristic.

A principal advantage of this rectifier circuit is that the maximum peak inverse voltage applied to the tubes is only $4\frac{1}{4}$ per cent greater than

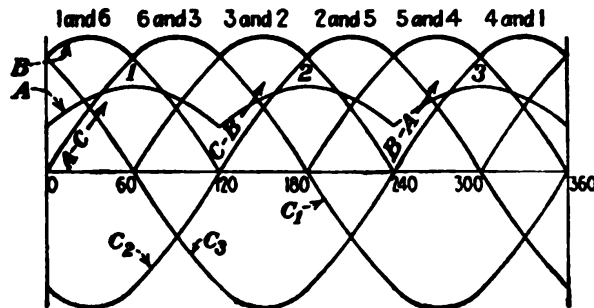


FIG. 6-17.—Output voltages of various rectifiers compared.

the average output voltage. The output wave form of this rectifier is a six-phase ripple which is easy to filter into an almost pure direct current.

e. Output Voltages of Three-phase Rectifiers.—A composite set of curves showing the output-voltage forms of three-phase rectifiers is shown in Fig. 6-17. Curve A shows the output from the half-wave circuit of Fig. 6-14. The characteristics of this circuit are such that only about 48 per cent of the maximum peak voltage is available as average output voltage. All these curves show the voltage conditions with a resistive load and no filter.

Curve B shows the output voltage from the half-wave, double-Y rectifier of Fig. 6-15 and from the full-wave circuit shown in Fig. 6-16. Both of these circuits give a six-phase ripple which does not require a large filter in order to give a pure direct-current output. The order in which the tubes function is indicated by the numbers at the peaks of each pulsation. The letters A-C, C-B, and B-A on the secondary e.m.f. curves (Fig. 6-17) indicate the path of the current through the transformer

¹ Peak voltage in this circuit is taken to equal 1.4 times the r.m.s. value of secondary voltage across each phase.

secondary on the full-wave rectifier. The labels C_1 , C_2 , and C_3 indicate the first, second, and third cycles, respectively.

6.14. Junction Rectifiers. *a. Description.*—Rectifiers of this class depend for their operation on the unilateral conductivity of certain metals when brought into contact. Two of these rectifiers which are finding practical use are the copper oxide rectifier and the magnesium-copper sulphide rectifier. The current flow in both types is from the mother copper to the copper compound, which results in the positive output terminal being connected to the copper and the negative terminal to the copper compound. The metals must make contact under high pressure in order that the separation between them shall not be more than the distance comparable to the molecular separation in the two metals.

b. Copper Oxide Rectifier.—The most recently developed type of copper oxide rectifier is based on the physical fact that, if pure copper is brought into atomic contact with cuprous oxide, the unit thus formed will offer a much higher resistance to the flow of an electric current in one direction than in the other. Actually this resistance is on the order of 3 to 1, that is, three times the resistance is offered in one direction than in the other. Rectification takes place between the copper and the cuprous oxide, and this action is electronic and not electrolytic in nature.

In order to work efficiently the copper oxide rectifier must operate cool, and for this reason the individual rectifier junction is made up in the form of a washer about $1\frac{1}{2}$ in. in diameter to which may be fitted cooling flanges if the rectifier is to be used for relatively high currents. Each washer is made of copper which is oxidized on one side. When assembled, electrical connection is made to the oxide by a washer of lead or metal foil. The construction and assembly of the rectifier are shown in Fig. 6-18.

Under practical conditions this type of rectifier works at efficiencies of 60 to 70 per cent. Although it is possible to assemble any number of units to give any practical power rating, this type of rectifier finds its greatest usefulness where only low voltages and power are required. The breakdown voltage per junction is 11 volts alternating current, and the breakdown temperature is about 160°F . The life of the rectifier will run into the thousands of hours, if the operating temperature is kept below 140°F . Tests have shown a life of 6 years for this rectifier with little or no deterioration. For proper operation the pressure on the units must be correct, and for this reason the rectifiers are assembled at the

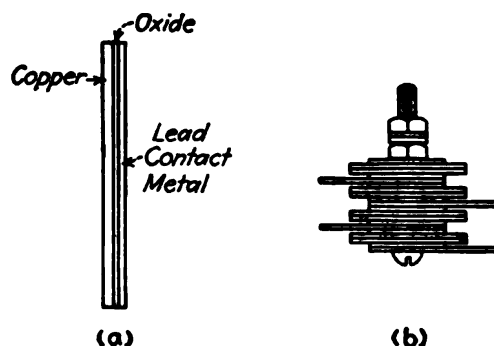


FIG. 6-18.—Junction rectifier unit.

factory and held together by a rigid clamp construction. The pressure should not be altered after the unit leaves the factory.

The copper oxide rectifier is made up commercially for use in meter conversion where it is used when it is desired to convert a direct-current meter into a universal meter for measuring both direct and alternating current. In this manner any direct-current milliammeter can, with the addition of this rectifier unit and the proper resistances, measure alternating- as well as direct-current voltages and current. It is also used together with other accessories such as a transformer and condensers to replace the dry cell in supplying current to the microphone, and for this purpose units are made to supply 15 ma. per button.

This unit is also used to supply direct current to excite the field coils of dynamic speakers. It was formerly used to a great extent for battery charging and for B eliminators, but the tube-type rectifier has largely replaced it for these purposes.

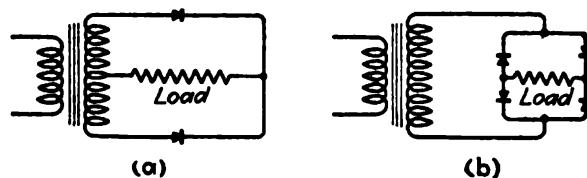


FIG. 6-19.—Two ways of connecting copper oxide rectifiers.

In broadcast-station operation the copper oxide rectifier is finding use as a low-voltage filament rectifier for station amplifiers, condenser microphones, and voltage amplifiers. It can be made to deliver 6 or 12 volts at current drains up to 7 amp.

The two standard ways of connecting the copper oxide rectifier are shown in Fig. 6-19. The bridge circuit in diagram (b) is perhaps the more desirable circuit for this type of rectifier as it reduces the strain on each unit by one-half.

c. The magnesium-copper sulphide rectifier is a dry junction-type rectifier which is made up of disks of magnesium and cupric sulphide in the form of washers assembled on a bolt and clamped together. A rectification ratio of 75:1 giving a resistance of 30 ohms to current in one direction and a resistance of 0.4 ohm in the other direction is secured. Proper operation depends on the elements being clamped together with a pressure of about 200 lb., and this pressure should not be changed by the user.

The safe operating voltage per junction is 4 volts, and the units are designed to operate at 90°C. (about 190°F.). The operating temperature may be raised to 150°C. without injury to the unit. The units are self-healing for minor breakdowns, and the life runs about 5,000 hr. There is, however, deterioration if this rectifier is left idle in a moist atmosphere.

This type of rectifier is best adapted to bridge circuits. Like the copper oxide rectifier before described, this rectifier has been largely replaced by tubes. It is finding some use, however, in dynamic loudspeakers for field excitation, and a more recent development has been the adaptation of this rectifier to voltage doublers and quadruplers for experimental and miscellaneous uses.

III. THE RIPPLE FILTER

6.15. Function of Ripple Filter.—The current delivered by a rectifier consists of a direct- and an alternating-current component. For all

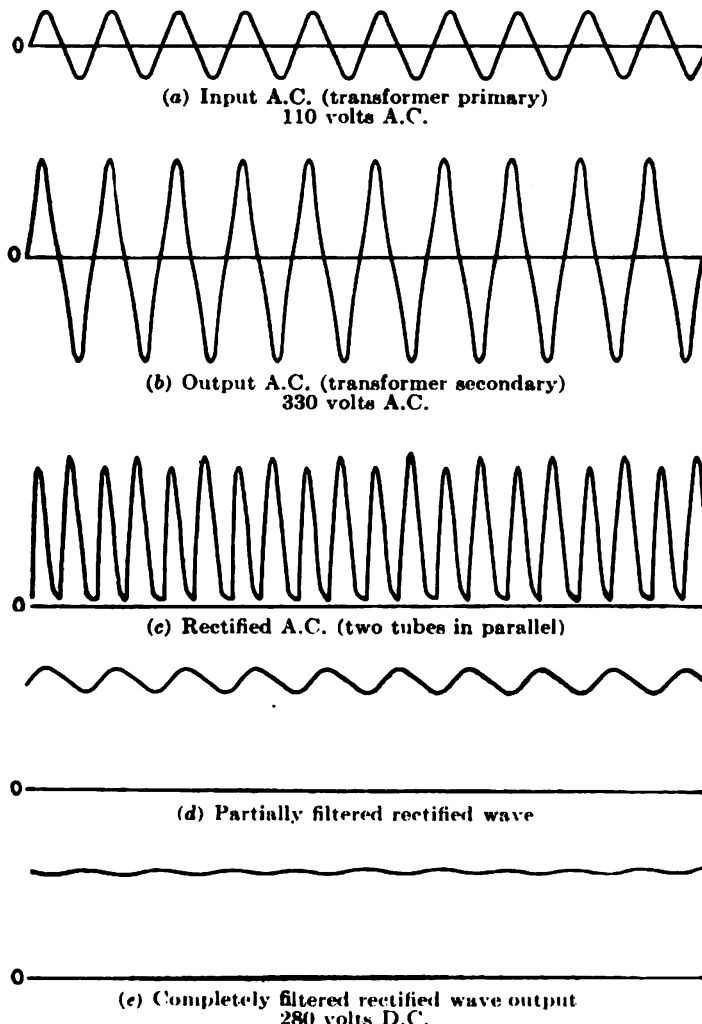


FIG. 6-20.—Rectified alternating current from input to output.

practical radio purposes this alternating-current component causes too much of a variation in the output of the rectifier to make the power thus delivered fit for use as plate power in vacuum-tube circuits. This variation would cause audio modulation of the emitted wave of the transmitter or of the output of the receiver fed by such a plate supply.

It is necessary, therefore, that this power be filtered, that is, its variations smoothed out.

A study of Fig. 6-20 will make clear the conditions in a typical rectifier circuit as a whole from input to output. Curve (a) is the alternating current flowing in the transformer primary and takes the form of a pure sine wave. In most instances this is a 60-cycle current, although in some places 50 cycles or even 25 cycles is supplied. The curve shown represents by its amplitude a 110-volt potential.

Curve (b) shows the output of the secondary of the transformer, which is also a pure sine wave. The voltage has now been raised to 330 volts. This is the reading that an alternating-current meter would register if connected across the secondary and is the effective or root-mean-square (r.m.s.) value of the voltage. The peak value of this voltage, that is, the potential strain to which the rectifier apparatus would be subjected, is found by the equation

$$E_m = E_{eff} \times 1.414$$

This formula, when dealing with tube rectifiers, is only of theoretical interest because the output of such a rectifier is erratic in nature and is not a pure sine wave. To arrive at the true peak values of a tube-rectifier output an oscillographic study must be made of the wave form. When this is not possible a generous safety margin must be allowed in figuring peak voltages.

Curve (c) shows the effect of a full-wave rectifier circuit on the transformer voltage shown in the preceding curve. Notice that there are two pulses of direct current for each alternation of alternating current. It is just as if the sine wave of the secondary voltage were folded along the zero line, the negative alternations becoming positive pulses by the rectifier action. It is interesting to note, too, that the effect of one tube is not exactly similar to the effect of the other tube, which accounts for the unevenness in the peak values of the rectifier because the tubes are not exactly balanced. In the particular curve shown the unbalance is not bad, but it serves to illustrate another source of unevenness in the output of the rectifier. Each cyclic variation tends to set up another alternating-current component which must be filtered by the filter.

Before discussing curves (d) and (e), the filter will be considered in detail.

All filters used in rectifier circuits are low-pass filters and as such are designed to pass currents of all frequencies below a critical or cutoff frequency and to reduce substantially the amplitude of currents of all frequencies above this critical frequency. This is shown graphically in Fig. 6-21, which is a graph of the typical performance of low-pass filters such as are shown in Fig. 6-22. The curve shows that when the particular low-pass filter represented by this graph is inserted in the line, the insertion loss at 20 cycles is 10 db, at 50 cycles, about 20 db, at 60 cycles, 24 db, at 120 cycles 35 db, and so on. Hence, it is seen that any low-frequency hum which gets through the filter is of a very low power value, the exact level depending, of course, upon the initial value of the ripple frequency.

This curve also shows the desirability of a high-frequency ripple output in that the high-frequency ripple suffers greater attenuation from the filter and, therefore, is easier to eliminate. The note on the graph reads, "Cross-hatched section indicates amount of attenuation." A

consideration of the situation will show this to be true. For example, suppose the ripple frequency is that from a three-phase full-wave rectifier such as is shown in Fig. 6-16, namely, a six-phase ripple resulting in

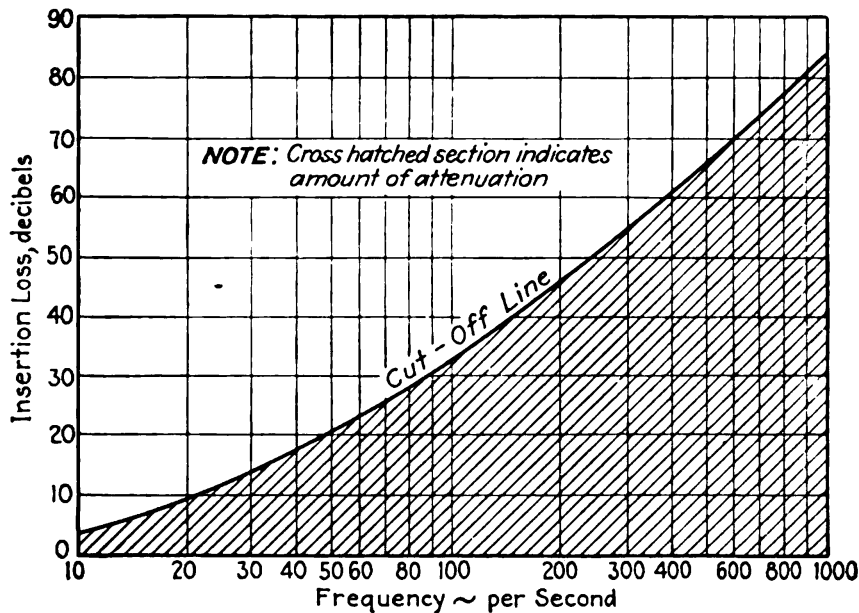


FIG. 6-21.—Low-pass filter performance graph.

360 cycles. By referring to the curve it is seen that the 360-cycle frequency is passed by the filter; but the loss is equal to 58 db. The initial power intensity would therefore have to be tremendous in order to be present in the output at all, and such a condition is unlikely in any situ-

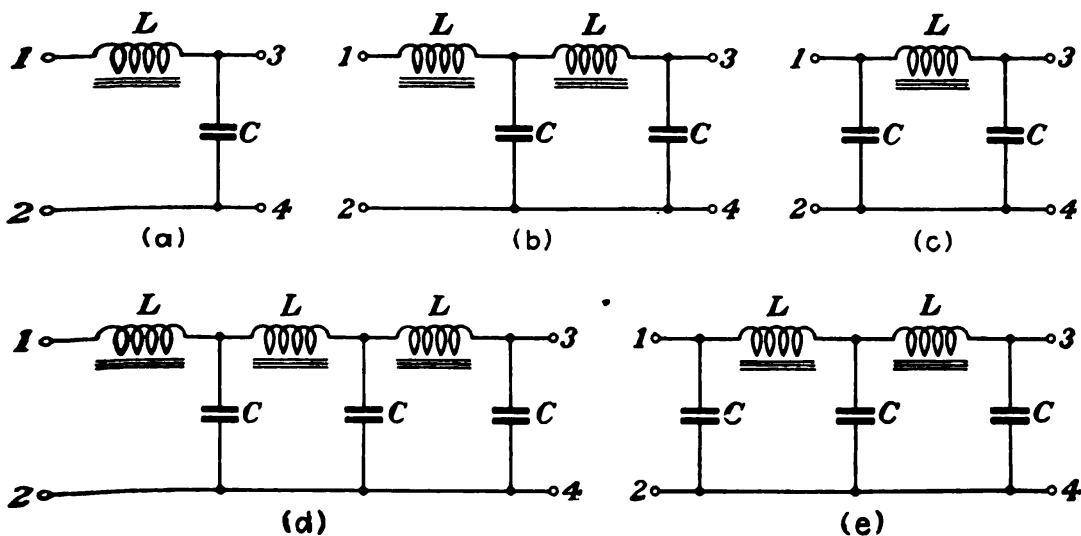


FIG. 6-22.—Various types of low-pass filter circuits.

ation. The rectifier filter is made up of audio or power chokes and condensers designed to withstand a high-potential strain. This type of filter is also known as a *ripple filter* because it reduces the ripple current, while freely passing the direct current from a rectifier or generator.

The ripple filter consists of a series-arm impedance which is always a choke coil or coils, and a shunt impedance which is always one or more condensers. The series arm, therefore, is always inductive reactance and the shunt arm is capacitive reactance. For method of deriving the values of L , C , and f_c , see Sec. 5.20.

Various types of ripple-filter circuits are shown in Fig. 6-22. The input or high end of the filter is designated by the numbers 1 and 2, and the output or low end of the filter by the numbers 3 and 4. Likewise, the line terminating in terminals 1 and 3 is termed the *high side* of the line, and the line terminating in the terminals 2 and 4 is called the low or ground side.

A ripple filter may have a condenser input as in Fig. 6-22(c) and (e), or it may have a choke-coil input as in circuits (a), (b), and (d). There is a considerable difference in the action of these two types of circuits as will be seen later. The condenser-input filter is used only with the high-vacuum type of tube rectifier while the choke-coil input filter is used with either the mercury-vapor- or high-vacuum-type rectifier.

The function of the choke coil in the filter is to smooth out the current fluctuations while the function of the condenser is to smooth out the voltage variations. Both working together constitute a ripple filter. In visualizing the operation of a filter, it is necessary to imagine the effect of inductance and capacity on an alternating current. The choke coil tends to oppose any change in the current in the circuit and depends for its operation on the counter e.m.f. it sets up when an alternating current flows through it. The source of the power is inconsequential; it may come from a direct-current generator and be the alternating-current component set up by the commutator ripple or it may be supplied by a tube rectifier; the action of the choke coil in limiting current peaks is the same in both circuits.

6.16. The Action of Filter Condensers.—When a condenser is connected across a rectifier, the following action takes place:

The first pulse of current passed by the rectifier puts a charge on the condenser. This charge is but a fraction of the total charge the condenser is capable of holding. As the tube is unilateral in conductivity, the charge can leak off the condenser only by flowing through the load. This it does slowly. Before it has all leaked off, however, another pulse of current comes along and increases the charge on the condenser. Therefore, as the discharge of the condenser is slower than the charge, the condenser finally becomes fully charged up to its rated capacity. Once the condenser is fully charged the discharge action becomes regular as in Fig. 6-23. As some period of time does elapse between pulses of current, the condenser discharges to a certain extent; so, its potential is lower at the beginning of each pulse than at the end of the pulse. This causes a fluctuation in the value of the voltage fed to the output by the condenser as shown in the curves in Fig. 6-23, E_c being the voltage fluctuations. The amount of this fluctuation has an effect on the final ripple in the output. Also notice that this fluctuation is greater when the time periods between charging pulses is greater. It varies directly with this factor. For this reason there is less ripple from a

full-wave rectifier [curve (b)] than from a half-wave rectifier [curve (a)]. It is also readily seen how the condenser voltage depends on the load. If the load permits the condenser to discharge too rapidly, the rectifier pulses will not charge the condenser rapidly enough to maintain the required voltage. For this reason, the output voltage of a rectifier unit decreases as the load increases, and vice versa. To decrease the condenser-voltage fluctuations, the condenser must be large enough in capacity to hold more electricity than can be drained off by the load in the time intervals between pulses. Also the rectifier must be of a sufficient rating so that it will be capable of charging the condenser up to the required potential.

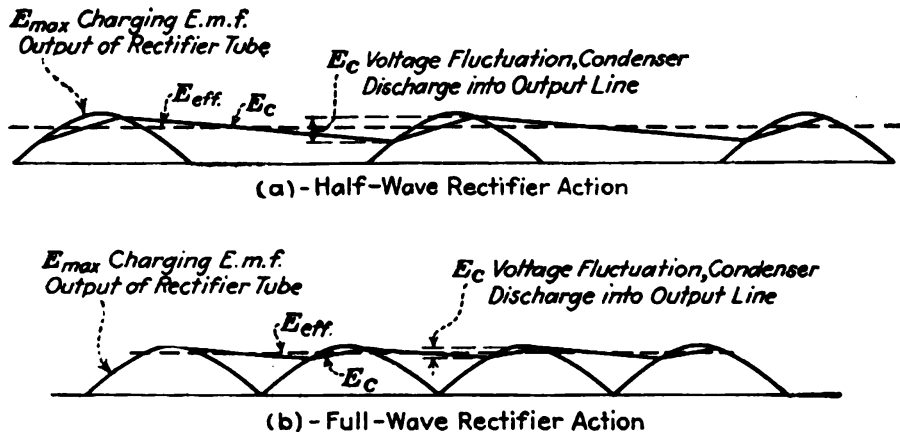


FIG. 6-23.—Condenser action in filter unit.

It has been found, from both theoretical solutions and practical tests,¹ that, of the condensers used in condenser-input filters, the first-filter condenser produces the greatest effect on voltage output and regulation but comparatively little effect on the ripple. The greater the capacity of the first condenser, within certain limits, the greater will be the voltage output of the filter circuit, and the better the voltage regulation. The second-filter condenser has a lesser effect on voltage output and regulation but a very important effect on the ripple. The last condenser in the two-section filter shown in Fig. 6-22(e) serves primarily as a reservoir to supply momentary high demands of the load.

Working voltage is the term applied to designate the potential at which the condenser should be worked for longest life in the circuit. This is an important factor in the design of ripple filters. A good practical rule is to specify as the working voltage of the first condenser of the condenser-input filter a value three times the output voltage, and for the following condensers a value twice the output voltage of the rectifier.

6.17. Paper Filter Condensers.—The conventional paper condenser consists of two metallic foils, which constitute the plates of the condenser, separated by a special dielectric paper. These sheets of foil and paper are laid one over the other and wound into a form not unlike the well-known bolt of cloth seen on the shelves of a

¹ The information in this and the next paragraph is condensed from a report on filter condensers in the *Aerovox Research Worker*, Vol. 4, No. 3.

dry-goods store. This form is then placed in a casing or container depending on whether the condenser is of the ordinary dry-paper type, or whether it is of the oil-impregnated or oil-filled types.

The area of the metallic foils, and the dimensions of the condenser container depend, of course, upon the capacity rating of the condenser. By the use of oil impregnation and filling, the physical dimensions for a given capacity are materially reduced.

In the oil-filled type the condenser is placed in a non-leakable container, and oil is poured in to fill up all air spaces. This oil has special properties, which will be mentioned in a moment, and naturally soaks into the dielectric, thus increasing the capacity of the condenser and its breakdown voltage. In the oil-impregnated condenser, the paper dielectric is impregnated with a special condenser oil having high dielectric strength together with a high dielectric constant similar to that used in the oil-filled type.

The plain paper condenser, not oil impregnated, is satisfactory for receiver power packs, and this type is available with breakdown voltages up to 1,000 volts. The paper condenser has, however, been largely replaced for this purpose by the electrolytic condenser later to be described.

For transmitting rectifying units the oil-filled or oil-impregnated condensers are preferable and are available with breakdown voltages as high as 3,000 volts or higher.

6.18. Electrolytic Filter Condensers.—The electrolytic filter condenser depends for its operation on the fact that certain metals when used as anodes in certain electrolytes become coated with a very thin insulating film due to polarization. This film acts as a dielectric separating the two electrodes constituting the condenser.

The *wet-type electrolytic condenser* is enclosed in a container which also holds the liquid electrolyte. Into the container is placed a number of corrugated aluminum plates which are bent into ridges to increase their surface area and, consequently, the capacity of the condenser. These aluminum plates are all connected together to form one electrode (anode) of the condenser. The electrolyte forms the other electrode. A flat aluminum plate is placed opposite each corrugated plate to serve as a means of passing current into the electrolyte. A film of oil is floated on top of the electrolyte to prevent evaporation.

Various types of electrolytes will operate in the electrolytic condenser; to mention two, there is ammonium citrate as one, and a solution of borax and boric acid in water as another. The latter is perhaps the most commonly used, it being non-combustible, non-poisonous, and non-injurious to clothing. The condenser works best at temperatures ranging from 40 to 105°F. Any heat over 105°F. will greatly shorten the life of the condenser, best operation being obtained at a temperature of about 75°F.

The electrolytic condenser has a unilateral-conduction characteristic, that is, it has an exceedingly high resistance to current flowing in one direction but a very low resistance to currents in the opposite direction. The voltage which may be impressed across the condenser before the film constituting the dielectric breaks down and permits an appreciable leakage current is called the *critical voltage* of the condenser. The voltage which may be impressed on the condenser safely without danger of rupturing the dielectric film is called the *working voltage*. At the present time the standard working voltage of the electrolytic condenser is 500 volts. This, of course, is below the critical voltage.

When a greater working voltage is desired, several condensers may be placed in series. But as this reduces the capacity, it may be necessary to use a series-parallel arrangement to get the required capacity.

Electrolytic condensers of the wet type find use as ripple-filter condensers on rectified low-voltage filament-supply lines. In view of their unidirectional properties these condensers must be connected to the line with the anode of the condenser to the

positive side of the line. If the connections are reversed, heavy currents will flow which would ruin the condenser.

Because of the thinness of the dielectric it is possible to get very high capacity values in a small space. For given areas of electrodes, capacities 1,000 times greater may be obtained with the electrolytic condenser than it is possible to get with a paper condenser. Electrolytic condensers have a poor power-factor (low efficiency) compared with paper condensers, but this is not a detriment of much consequence in ripple-filter circuits.

Great care must be taken to keep impurities out of the condenser. The containers must be clean and the aluminum especially pure. Impurities of any kind, especially organic, will materially shorten the life of this type of condenser. To keep the film on the anode, it is advisable to keep the condenser continually across a live circuit, and it should be connected across such a circuit for not less than 1 hr. each week at a minimum.

Dry electrolytic condensers operate on the same principle as the wet type just described but differ somewhat in mechanical construction. The electrodes consist of foil which is an alloy of aluminum and which may be wound into a roll form and placed in a tubular container. These electrodes are separated by a gauze, usually of double thickness, which is soaked with the electrolyte.

One well-known type of dry electrolytic condenser utilizes for its electrolyte a solution of boric acid, glycerine, and ammonia, either gaseous or as an ammonia water, in the proportion of 1,000 grams of glycerine, 620 grams of boric acid, and about 50 cc. of 26 per cent ammonia water or gas. This results in a fluid with which the gauze is impregnated. The dry electrolytic condenser is dry only in the sense that its electrolyte cannot under any circumstances spill out as it is held by the gauze.

In all other respects the theory of operation of the dry electrolytic is identical with that of the wet electrolytic condenser.

6.19. The action of the choke coil in a ripple filter is deserving of study because of its important function in the circuit.

If a choke coil of a certain rating in henrys is inserted in an alternating-current line, its rating remains constant so long as the frequency and current remains constant. The inductive action of the choke, as we have seen before, is due to the action of the lines of force cutting the windings of the choke and setting up a counter e.m.f. which tends to prevent any change in the current flowing through it. It has the same effect on an alternating current that a flywheel has on the motion of a steam engine; it tends to keep its variations at a minimum and its operation smooth. A choke coil placed in a direct-current line would affect the circuit only as a resistance; as there are no moving lines of force about the coil, there can be no inductive effect. Likewise, if for any reason the number of lines of force which cut the coil for a given time are reduced, the inductive effect of the coil is reduced.

A choke coil in a ripple filter has flowing through it principally direct current. In addition to this it has an alternating-current component which sets up moving lines of force about the coil, caused by the rise and fall of each pulse of direct current. When the pulse is rising in value, the lines of force are going out from the coil in a given direction, outward from the center of the wire to infinity. Also, when the pulse is decreasing in value, the lines of force are collapsing on the coil. In this way there is a constantly moving field of force cutting the coil windings, first in one direction and then in the other, resulting in the setting up of an opposing current. It is this opposing current which tends to smooth out the ripple in the output of the power supply.

Every choke coil has a current saturation point above which the effectiveness of the choke decreases rapidly. The direct current flowing through the choke coil in the ripple-filter circuit raises the flux to a certain percentage of the saturation value. If this direct current is raised to a point where it increases the flux of the choke well above the saturation point, it is readily seen that the alternating-current component can have no effect because any change in the flux above the saturation point has no effect on the coil as a choke. If the direct current is now reduced to the saturation point, the coil will have a slight inductive value owing to the decrease in flux below saturation by every negative alternation of alternating-current component; but every increase above the saturation point has no effect, and, therefore, the coil has but little inductive value.

The choke to operate efficiently must not have more than a certain amount of direct current flowing through it. This amount is limited to a point which still allows a margin for the alternating-current component to affect the coil. The change in flux in this margin must be great enough to produce the inductive effect of the coil.

A choke coil for a ripple filter is rated, therefore, to have a certain inductive effect with a certain direct current flowing through it. Any increase or decrease in this direct current will change the inductive value from the rated value. It is important, therefore, to choose a choke coil capable of operating efficiently with the direct-current load the circuit must handle.

As the direct-current resistance of the choke causes a loss of voltage, which must be subtracted from the amount delivered by the rectifier, this resistance must be kept as low as possible.

A choke coil for a ripple filter may be rated 15 henrys, 150 ma., 210 ohms, which means that as long as the current through the choke is not raised above 150 ma. the coil will have an inductance value of 15 henrys. The power loss in the choke may be computed by the familiar I^2R formula, and the voltage drop is figured $E = I \times R$.

Iron-core choke-coil inductive values (henrys) are usually measured with 60-cycle alternating current. There is but little difference in the inductive value of a choke, when the frequency is raised to 120 cycles. For values of frequency higher than 120 cycles the inductive value of the choke would have to be remeasured if an accurate rating is desired. For example, if a choke is rated at 30 henrys it means 30 henrys at 60 cycles. It could still be considered 30 henrys at 120 cycles from a practical standpoint. Therefore, if a 30-henry choke is specified for a single-phase full-wave rectifier, where the ripple frequency is 120 cycles, any 30-henry choke could be used. On the other hand, if a 15-henry choke is specified for a three-phase full-wave rectifier it would mean a choke having an inductance of 15 henrys at a ripple frequency of 360 cycles. The ordinary 15-henry choke would be more than 15 henrys at this frequency and would be a larger choke than necessary.

Retard or retardation coil is another name for a ripple-filter choke, although a retard coil may have other functions if used in another circuit. This is the designation generally used by the Western Electric Company in their apparatus descriptions. The filter choke is also known as a *reactor*, which designation is generally used by the RCA in their apparatus descriptions. A reactor may or may not have an iron core depending on its use in the circuit, although all ripple-filter reactors utilize iron cores.

6.20. The first choke coil in the circuits used with the mercury-vapor tube [Fig. 6-22(a), (b), and (d)] has a very important function in preventing current peaks from reaching a value high enough to damage the filament of the rectifier tube. Important experimental work¹ has shown

that this choke has a certain *critical value* which may be expressed for 60-cycle circuits by the equation

$$L_o = \frac{R}{1,000} \quad (4)$$

where L_o is the critical value and R the resistance of the load. The optimum value (the value which works best) in a filter circuit is $2L_o$ or twice the critical value.

In addition to protecting the mercury-vapor tube against excessive current peaks, it improves the smoothing action of the filter, greatly improves regulation of voltage, and reduces heating of the secondary winding of the transformer.

In radio circuits, such as in class B and C amplifiers, where the maximum load current drawn from the rectifier is subject to wide variation, the first choke coil must function with widely differing load currents. Such a choke is called a *swinging choke*. The inductance value of the swinging choke does not fall below the critical or safe value at maximum load-current peaks. The critical value required varies directly with the load current. That is, at the maximum load current the critical value of inductance required is low, and vice versa, making for a considerable swing or variation in the inductance value the choke must provide. To reduce the range of this swing, a bleeder current (see next section) sufficient to maintain the swinging choke above the critical value is used. The required inductance at the critical value is secured in a swinging choke by using a choke with little or no air gap in the core. Hence, the inductance value is relatively high even though the current is low. In the final analysis, therefore, the true function of the swinging choke is to improve the regulation of the circuit and keep this regulation at a satisfactory value.

The choke connected before the first condenser is a necessity in all mercury-vapor rectifier circuits. As this type of rectifier is rapidly replacing the high-vacuum type in modern transmitting equipments, a series inductance or first choke usually precedes the first shunt condenser in the rectifier units accompanying these outfits.

6.21. Equalizing and Bleeder Resistance.—If it is necessary to connect several condensers in series across the output of a power supply, condensers of unlike capacity ratings should not be used, as under these circumstances the voltage distribution across the individual condensers will be uneven, the smallest condenser taking the highest voltage drop. It is better practice to use condensers of equal-capacity rating when a series bank is used.

When a number of condensers are connected together to form a series bank, it is advisable to connect an equalizing resistance across the

¹ See article by Dellenbaugh and Quimby in *QST*, February, 1932.

entire bank to equalize the voltage drop across each condenser unit. When such a resistance is provided, each unit has a tendency to maintain across itself a voltage equal to that across each of the other units. A schematic diagram showing the equalizing resistor in position is shown in Fig. 6-24. The purpose of the resistance is, of course, to equalize the strain across each condenser of the series bank.

The resistance value of the equalizing resistance should be such that the current drain by the resistor is not excessive. A drain of 10 to 25 ma. is satisfactory in most instances.

Under any circumstances it is advisable to connect what is known as a *bleeder resistance* across the output of a rectifier unit, provided an equalizing resistor is not used. As before explained, this is to prevent excessive voltages from breaking down filter condensers, which might occur if the load were suddenly removed from the output. The load might be removed in a radio-telephone or telegraph transmitter if a tube in the load circuit burned out, or, in the latter, during keying. In a

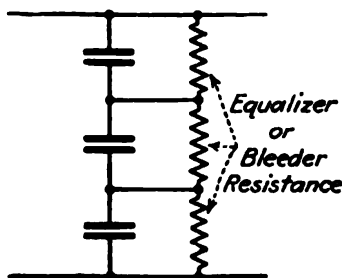


Fig. 6-24.—Bleeder resistance connection.

receiver or audio amplifier, the load might be removed if a tube burned out or was removed with the current on.

In power packs supplying power to receivers, the function of the bleeder resistance is performed by a section of the voltage divider, as will be explained when voltage dividers are discussed later. On the other hand, in rectifier units provided for transmitters, and in other circuits where no voltage divider is needed, the bleeder resistance is necessary not only to prevent condenser breakdown but to improve the regulation of the voltage output during the keying if a radio-telegraph transmitter is employed.

The value of the bleeder resistance in transmitting circuits depends on conditions in the circuit. A value of bleeder current equal to 25 or 30 per cent of the total drain on the rectifier unit is used in many installations with success. The value of bleeder resistance is calculated by Ohm's simple law $R = E/I$, where E is the voltage drop across the resistor and I the bleeder current.

Bleeder resistances are sometimes variously known as *drain resistors*, *stabilizing resistors*, or simply as *load resistors*. The bleeder resistance, in addition to its functions already discussed, serves to remove all static

charges from the power-filter condenser after the transmitter is shut down. This action protects the operator against accidental shock should he come into contact with these power circuits.

6.22. Voltage Dividers.—When the voltage has been rectified and filtered, it is ready to be applied to the vacuum-tube circuits of the transmitter or receiver. Except for simple one-tube circuits, it is nearly always necessary to apply different voltage values to various elements in the tube and to the various tubes or sets of tubes. In order to secure these different voltages, it is necessary to provide a separate power supply for each voltage or to divide the output of a single power supply into the various values desired. As it is usually uneconomical and unnecessary to provide a separate power supply for each voltage, one or two power supplies provide all the necessary voltages, for even a complicated radio circuit, when the output of the supply is divided by a voltage divider.

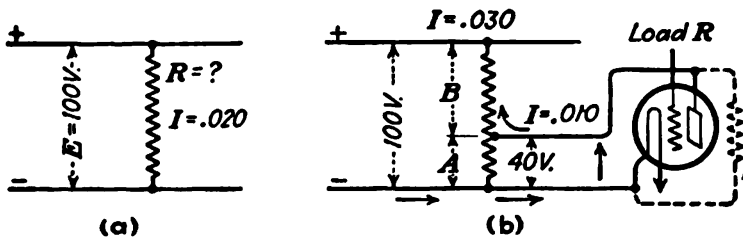


FIG. 6-25.—Fundamental circuit of voltage divider and tube-load connections.

A voltage divider is very simple in its operation and functions entirely in accordance with Ohm's law. The development of an elementary voltage divider is shown in Fig. 6-25. In diagram (a), if the voltage is 100 volts and the current is 20 ma., the resistance R is found by the equation

$$R = \frac{E}{I} = \frac{100}{0.020} = 5,000 \text{ ohms}$$

It is seen then that, if the voltage and current are known, the value of the resistor R is easily found. Also, if any two of the values E , I , or R are known, it is simple to find the third by the application of Ohm's law.

Suppose now it is desired to tap off 40 volts from a resistor (voltage divider) across a 100-volt line. How much resistance must be used? The answer to this question depends on the load to be connected across the 40-volt line. For illustrative purposes let us assume that the load is to consist of a vacuum-tube circuit which draws 10 ma. Reduced to an elementary basis, the circuit appears as in Fig. 6-25(b). In this circuit we have a resistance B in series with a parallel circuit consisting of resistance A and the tube load R . Now we know that the voltage drop across B must be the total line voltage, 100, minus the drop of 40 volts across the unit AR , or 60 volts. The next value we must have to progress

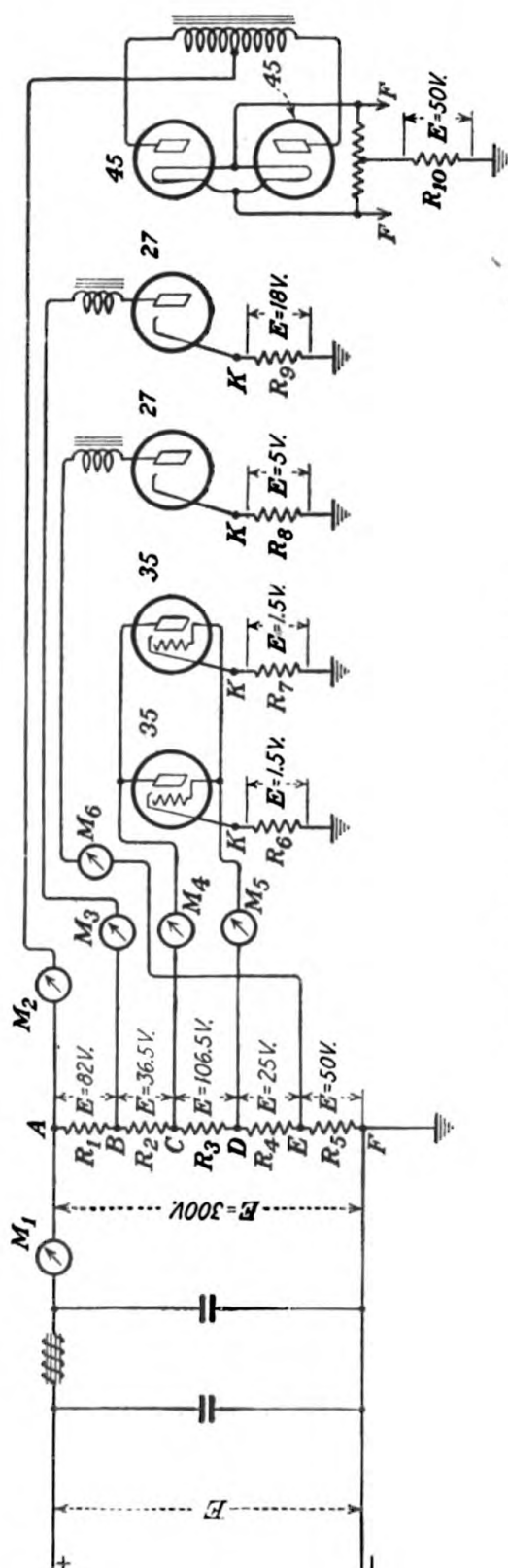


FIG. 6-26.—Typical voltage-divider circuit.

with the calculation is the current value I which will flow through B . If we allow a bleeder or stabilizing current of 20 ma. through A , which is the usual practice, and 10 ma. flow through R , a total of 30 ma. will flow through B . Applying Ohm's law we get

$$R_B = \frac{E}{I} = \frac{60}{0.030} = 2,000 \text{ ohms}$$

The value of R_A is found by realizing that 10 ma. goes through the load R and 20 ma. goes through the bleeder section A of the bleeder resistor. The value of R_A is, therefore, found by the Ohm's-law equation $R = E/I = 40/0.020 = 2000$ ohms.

The power expended in section A , which may be found by the conventional I^2R formula is $0.020^2 \times 2,000 = 0.8$ watt. The power expended in section B is $0.030^2 \times 2,000 = 1.8$ watts. There is, therefore, a total of 2.6 watts expended in the voltage divider. The power expended in the load R may be computed by the simple equation

$$\text{Watts} = R \times I = 40 \times 0.010 = 0.4 \text{ watt}$$

The total drain on the power supply is the sum of the power expended in the voltage divider plus the power expended in the load, 3.0 watts.

Unless there was a need for the 100 volts potential, this would hardly be an economical way to provide power for this load, as more power is wasted in the voltage divider than is used in the load. However, if a potential of 100 volts is needed for one purpose and a potential of 40 volts is needed for another purpose, it would probably be more economical to get the 40 volts by means of a voltage divider than to provide a separate source of supply. It is situations of this kind that make a voltage divider desirable from an economical point of view.

It is well at this point to consider the type of resistors which would be suitable for the voltage divider explained. In section A the power expended is 0.8 watt. *It has been found that resistors show better constancy of value and longer life if they are worked at but 50 per cent of their rated power-carrying capacity.* Therefore, resistance A should have a rating of at least 1.6 watts. As a resistor of this capacity is not a stock item, it would be necessary to use a 2-watt resistor. Resistor B expends 1.8 watts, and it would be necessary to use a 4-watt resistor in this position, although a 10-watt size would be safer.

Any circuit in which a voltage divider is necessary can be reduced to a simple schematic diagram. Another example of this method is shown in Fig. 6-26. Assume that it is required to design a voltage divider to supply a number of tubes for a vacuum-tube receiver as indicated in the following list.

Radio-frequency amplifier using two 35 screen-grid tubes.

Detector using one 27 tube.

Audio-frequency amplifier using one 27 tube.

Power amplifier using two 45 tubes.

It will first be necessary to ascertain the plate and screen voltages and the total plate- and screen-current drain from a tube-characteristic table. In this example the various voltages and total drain for each tube are as follows.

	Radio frequency 35	Detector 27	Audio frequency 27	Power 45
E_p	180 volts	45 volts	200 volts	250 volts
I_p	0.0058 amp.	0.0002 amp.	0.0051 amp.	0.034 amp.
E_c	1.5 volts	5 volts	18 volts	50 volts
$E_{s,g}$	75 volts			
$I_{s,g}$	0.0025 amp.			

The total drain for all tubes will be

Two 45 $0.034 \times 2 = 0.068$ amp.
 One 27 (A.F.) $0.0051 \times 1 = 0.0051$ amp.
 One 27 (DETECTOR) $0.0002 \times 1 = 0.0002$ amp.
 Two 35 (R.F.) $0.0058 \times 2 = 0.0116$ (plate) amp.
 $0.0025 \times 2 = 0.005$ (screen) amp.
 Total drain = 0.0899 amp.

To this must be added a bleeder current of between 10 and 30 ma. to accommodate increases in plate current due to signal-grid swings. This will insure a maximum degree of stability and prevent load variations in the power supply and its associated circuits.

In this example, we shall assume a bleeder current of 25 ma., or 0.025 amp.

Therefore the total drain to be delivered by the supply as indicated by the meter M_1 will be $0.0899 + 0.025 = 0.1149$ amp. From this value a current of 0.068 amp. will be delivered to the circuit M_2 . The remainder, or 0.0469, must then pass through the resistance R_1 . Before calculating R_1 , however, it must also be remembered that the total voltage across the divider between the points A and F must be 300 volts in order that 250 volts may be applied to the two power tubes. The value of 300 volts is required because there will be a voltage drop of 50 volts across the biasing resistance R_{10} . Now the drop across R_1 , necessary to decrease the voltage for the 227 audio-frequency tube to 200 volts, must be calculated on the bias of $200 + 18$ volts, the 18 volts being necessary to compensate for the biasing voltage lost across the resistance R_9 . Hence, to calculate the value of R_1 , we divide the drop necessary by the current flowing through it, $E_{AB} = 300 - 218 = 82$ volts. Since 0.068 passes through the circuit M_2 , the remaining current through R_1 must be $0.1149 - 0.068$, or 0.0469

$$R_1 = \frac{E}{I} = \frac{82}{0.0469} = 1,748\omega$$

amp. Thus R_1 establishes an e.m.f. of 218 volts between the points B and F and an effective e.m.f. of 200 volts between the plates and filament of this tube.

Now, since the remaining current through R_2 to tap C is $0.0469 - 0.0051$ or 0.0418 amp., because 0.0051 is taken away by the circuit M_3 , and since R_2 must drop the voltage to 181.5 , or a drop of 36.5 volts (1.5 volts being allowed for the drop in the biasing resistors R_6 and R_7),

$$R_2 = \frac{E}{I} = \frac{36.5}{0.0418} = 874^\omega$$

The potential for the next tap, D , is then determined, since the screen grids in this circuit require a potential of 75 volts between D and F , or a drop of 106.5 volts.

The value $I = 0.0302$ is obtained by taking the difference between the current at point C and that taken by the circuit M_4 ; thus $0.0418 - 0.0116 = 0.0302$. Hence R_3 may be calculated thus:

$$R_3 = \frac{E}{I} = \frac{106.5}{0.0302} = 3,526^\omega$$

Since the voltage for the detector tube from tap E must be 45 volts, the next resistance, R_4 , must drop the voltage to $45 + 5$ (R_5) or 50 volts, a drop of 25 volts.

The value $I = 0.0252$ is obtained by taking the difference between 0.0302 (at point D) and the current taken by the circuit M_5 ; thus $0.0302 - 0.005 = 0.0252$. Hence,

$$R_4 = \frac{E}{I} = \frac{25}{0.0252} = 992^\omega$$

Now, since the last circuit M_6 will require a current drain of 0.0002 amp., the value of R_5 may be readily calculated. I is calculated: $0.0252 - 0.0002 = 0.025$.

$$R_5 = \frac{E}{I} = \frac{50}{0.025} = 2,000^\omega$$

The power dissipation for each resistance may then be calculated by the formulas I^2R or $E \times I$. The latter is preferable in this problem, since the voltages across each resistance have already been established.

IV. GENERAL RECTIFIER CONSIDERATIONS

6.23. Ripple frequency¹ is determined by the number of direct-current pulses delivered by the rectifier to the circuit per second. Assuming a 60 -cycle current as standard, the ripple frequency for the various rectifier circuits before the filter is applied is as follows:

Circuit	Ripple Frequency, Cycles
Single phase:	
Half wave.....	60
Full wave.....	120
Full wave (bridge circuit).....	120
Voltage doubler.....	120
Three phase:	
Half wave.....	180
Half wave (double-Y).....	360
Full wave.....	360

¹ The problem of ripple-filter design is beyond the scope of this text. Readers interested in this phase of the subject are referred to the references which follow:

DELLENBAUGH JR., F. S., and R. S. QUIMBY, *The Economical Design of Smoothing Filters*, *QST*, April, 1932.

JOHNSON, C. A., *Electric Filter Design*, *Radio News*, March, 1932.

The higher the ripple frequency, the easier it is to filter, that is, the smaller will be the values of L and C necessary in the filter.

The output wave form from a rectifier power supply depends on the effectiveness of the filter. Curve (d), Fig. 6-20, shows the wave form for an inadequately filtered supply, and curve (e) shows a well filtered wave form. To appreciate fully the effect of the ripple filter, curves (c) and (e) should be compared.

Multi-section filters are necessary if a single-section filter, diagram (a), Fig. 6-22, does not attenuate the ripple frequency sufficiently. A double-section filter would be drawn as in diagram (b), whereas a single-section filter preceded by a shunt condenser would be shown as in diagram (c). Diagram (d) is a three-section filter, whereas diagram (e) is a double-section filter preceded by a shunt condenser.

Filters Compared.—The output voltage from a choke-input filter is lower than if a condenser-input filter were used in its place. On the other hand, a rectifier equipped with a choke-input filter can be overloaded more without damaging the rectifier tubes than if a condenser-input filter was used. Of course, if mercury-vapor tubes are used, a choke-input filter *must* be used to protect the filament against excessive current surges.

6.24. Losses in Rectifier Apparatus.—The output voltage of the rectifier power supply is the voltage of the transformer secondary passed by the tube minus the loss in the rectifier tube and the filter. At first glance this might seem inconsequential, but it sometimes amounts to a considerable loss. As has been before pointed out, the loss in a high-vacuum type of rectifier depends on the amount of current being passed by the tube and may amount to a value of from only a few volts to several hundred volts. The loss in such a tube could be determined only by an inspection of the characteristic curve of the tube showing its voltage drop at various loads. The loss in a mercury-vapor tube regardless of the load is 15 volts under normal operating conditions. If two tubes are used in series, as in a voltage doubler or bridge circuit, the voltage loss is twice that of one tube.

The voltage loss in filter chokes may be figured by the formula $E = IR$. For example, a 15-henry choke with a resistance of 200 ohms passing 150 ma. would have a drop (loss) of 30 volts. If two such chokes are used in the circuit, the loss would be twice 30, or 60, volts. The power loss in each choke would be $I^2R = 0.0225 \times 200 = 4.5$ watts; in two such chokes the loss would be 9 watts.

6.25. Typical rectifier and filter systems are shown in the diagrams in the various chapters on receiving and transmitting apparatus. When the study of this chapter has been completed, these practical circuits should be studied with the view of thoroughly associating theory and practice.

Ripple filters for generators are described in Chap. 17, Dynamo-electric Machinery. An inspection of the diagrams of transmitters using motor generators as a source of power will show the methods of connection employed and the values of condensers and chokes used.

6.26. Plate Fuses.—In the low- and intermediate-power transmitters, where circuit breakers or relays are not provided in the plate circuit, fuses may be inserted in the plate leads of the rectifier tubes (as well as in other tubes). The current-carrying capacity of these fuses must be such that they will afford the tube ample protection against overloads. Generally the normal load is from one-half to two-thirds the fuse rating. An inspection of any "parts" catalogue will give the reader an idea of the capacities of these fuses. They afford a very inexpensive insurance against tube damage from overloads.

6.27. Rectifier Troubles.—Troubles in the rectifier circuit show up as faulty circuit operation in either the transmitter or receiver for which the rectifier is the source of power supply. Perhaps the most common trouble is that of a faulty rectifier tube. If a high-vacuum type of tube is used, a faulty tube may be detected by a decrease in the output voltage of the rectifier. If a mercury-vapor tube is used, a faulty tube may be detected by the absence of the customary "healthy" blue haze appearing when the rectifier is in operation. The lack of a blue haze may be caused by air coming into the tube or by filament deactivation. Regardless of the cause, the tube will have to be replaced. It is important that the filament voltage of the rectifier be held constant at its proper value.

No output voltage from the rectifier may be due to faulty relays in the circuit the contacts of which need cleaning, or the armature of which needs bending to make it rest flat against the pole pieces. See that all relays are operating properly. The same holds true for door switches on transmitters, all of which must be closed for normal operation.

An incorrect load on the voltage divider caused by a ground or open circuit in equipment would cause trouble in the rectifier affecting its output and possibly burning out the voltage-divider section or sections affected.

Sometimes a type of sizzling interference called *hash* is encountered with mercury-vapor rectifiers. This trouble is caused by the sudden vaporization of the mercury vapor at the start of each alternation. The remedy is a grounded shield can placed over each rectifier tube and a radio-frequency choke in each plate lead at the rectifier-tube socket.

A common cause of trouble in a rectifier system is the blowing out or breaking down of a condenser. This is usually due to excessive current surges which strain the condenser above its working voltage point. To guard against condenser breakdown, condensers with a working voltage well above the maximum surge voltage must be used.

A defective condenser may be detected by a continuity test using a voltmeter and battery in series across the condenser terminals. If the condenser is in good condition, the voltmeter will show a temporary deflection when the voltage is applied across the condenser showing that the condenser is absorbing a charge. When the condenser is charged the deflection drops to zero. If the condenser is short-circuited by connecting together its terminals after this test is made, a flash will occur as the condenser discharges just before the connection is made. This is further proof that the condenser is in good condition. If the condenser is short-circuited internally, owing to breakdown of the dielectric by excessive potential, a continuous deflection will be noted on the voltmeter.

A defective choke coil could be located by a similar continuity test, using a voltmeter and battery. An open choke coil would, of course, be indicated by no deflection on the voltmeter. A choke with part of its winding internally short-circuited would be indicated by a higher reading on the voltmeter than is secured by comparison with a perfect choke of the same type and size. Troubles in rectifier circuits can usually be located by continuity tests using a voltmeter or buzzer in series with a battery across the parts to be tested.

V. ELECTRICAL INDICATING INSTRUMENTS

The radio engineer, technician, or operator spends so much of his time watching meters that a knowledge of their working principles is in order. The power-switchboard meters most commonly employed in

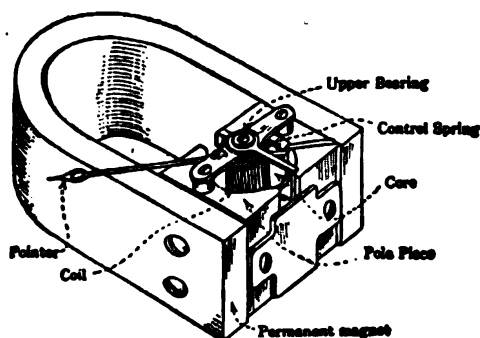


FIG. 6-27.—D'Arsonval movement for electrical indicating instrument.

radio stations may be grouped as follows: ammeters, voltmeters, frequency indicators, wattmeters, and ampere-hour meters. These instruments are designed to operate on direct or alternating currents.

6.28. Voltmeter for Continuous E.M.F.—Most direct-current voltmeters operate on the principle of the D'Arsonval movement which depends for its operation on the torque produced on a conductor by a field of force. In modern applications of this principle to voltmeters a rectangular coil of fine copper wire is fixed to revolve between the soft-iron core and pole pieces of a permanent magnet as shown in Fig. 6-27. This class of instrument commonly known as the *moving-coil* type is comparable in operating principle to a small electric motor.

The terminals of the moving coil are connected across the potential to be measured. The effect of the current flowing in the coil sets up a

north and south pole in the coil which then tends to orient itself with respect to the magnetic poles of the permanent magnet between which it is fixed to revolve. The amount of twisting depends upon the current flowing in the coil, and it is, therefore, possible to use it as a current-measuring instrument calibrated as a voltmeter.

Because the voltmeter is *always* connected directly across, or in shunt to, the line, a *current-limiting resistor* must be connected in series with the moving coil. Generally for voltages up to 150 volts this resistance is mounted inside the meter. This resistance is of such a value that the amount of current flowing through the coil is just enough to give the required deflection, and the movement of the needle, attached to the coil (see illustration) across the indicating scale, is uniform regardless of the potential value applied to the meter terminals. It is, therefore, possible to calibrate the meter to read any value of voltage up to its maximum capacity by merely changing the value of the resistance in series with the moving coil. Multi-range meters are in fact arranged with this series resistor tapped at different values to give the desired readings. The range values are so chosen that they are multiples or submultiples of one another and can be readily marked on the scale.

For voltages greater than 150 volts, the series resistor is usually so large that it cannot be placed in the meter case and is generally supplied as a separate unit. For this type of meter, when of the portable type, it is the usual practice to supply several different values of resistances so that the range of the meter can be made flexible to suit conditions. These series resistors are called *multipliers*, and a meter must be used only with the multiplier or multipliers for which it is calibrated, otherwise the readings will be erroneous.

A study of Fig. 6-27 will show how the meter is constructed. The pointer is attached to the moving coil as shown, and a small spring is provided which serves to bring the coil back so that, with no e.m.f. applied, the pointer points to zero on the scale. If a meter must be repaired for any reason, it generally requires recalibration at the same time.

As the D'Arsonval movement will give a forward deflection only when the current is flowing in a certain direction, the terminals of voltmeters employing this type of movement are marked with polarity signs. For this reason, voltmeters may be used to determine the polarity of direct-current circuits.

Figuring Multiplier Values.—Suppose a certain D'Arsonval movement has a resistance of 2.5 ohms, and that it takes 0.030 amp. for full-scale deflection. Then, $E = I \times R = 2.5 \times 0.030 = 0.075$ volt, or 75 mv., for full-scale deflection of the movement, that is, without any resistance in series with the moving coil.

For example, suppose it is desired to utilize this movement as a voltmeter to read 150 volts, what must be the value of the multiplier?

The resistance value of the multiplier must be such that it will have a drop of $150 - 0.075$ or 149.925 volts across it when 0.030 amp. is flowing through it. Hence,

$$R = \frac{149.925}{0.030} = 49,975^{\omega}$$

It is useful for the radioman to know that any direct-current milliammeter can be converted into a voltmeter by connecting a suitable multiplier (R) in series with it. The value of the resistance may be found, as explained above. For example, suppose it is desired to convert a 0 to 5 milliammeter into a voltmeter to read 500 volts. Then, $R = E/I = 500/0.005 = 100,000$ -ohm multiplier necessary. When the range desired exceeds 10 volts and the resistance of the meter is extremely low, compared to the total R , as is usually true, this small meter resistance can be neglected as is done here. For very accurate readings the converted meter would need to be calibrated against a standard meter.

The resistance of a voltmeter includes the resistance of the moving coil, plus total multiplier resistance, plus the resistance effect of any shunt resistances. Thus a 30,000-ohm voltmeter is a voltmeter the R of which measures 30,000 ohms between its terminal posts.

High-resistance voltmeters are used to measure voltages on circuits where the current drain is small. The reason for this is apparent when it is realized that any appreciable current drain by the meter makes a consequent change in the voltage of the circuit, and the meter would not show true operating voltages. Because of this, voltmeters for plate-supply and bias-voltage measurements usually have a resistance of about 1,000 ohms per volt, that is, a 0 to 50 voltmeter would have a resistance of 50,000 ohms. The ordinary portable voltmeter has a resistance which usually varies between 50 and 150 ohms per volt depending on the type of meter.

6.29. Ammeter for Direct Current. *a. Description.*—This instrument is constructed along the same lines as the voltmeter for direct current previously described, using the D'Arsonval movement, except that the moving coil of the ammeter is wound with a heavier wire and is of a lower resistance, usually from $\frac{1}{2}$ to 1 ohm in American instruments. The ammeter, as far as movement alone is considered, is a millivoltmeter¹, and, in fact, reads millivolts, which are directly proportional to the current flow. Ammeters can, therefore, be calibrated in amperes or milliamperes as desired.

The ammeter is always used in conjunction with a *shunt* which is a predetermined length of conductor of a specified resistance across which the ammeter is connected. The way in which the shunt and the ammeter are used in the circuit is shown in Fig. 6-28. The purpose of the shunt is to by-pass, or sidetrack around the meter, the greater part of the current being measured, thus making it unnecessary for the meter to carry much current in order to give an accurate reading.

The shunt is constructed by silver-soldering strips of a special alloy called *manganin* between two heavy copper lugs. The manganin strips act as the resistance across which a voltage drop occurs which voltage

¹ Instrument is a current-reading device but may for convenience be considered in this case as a millivoltmeter.

drop is measured by the millivoltmeter calibrated as an ammeter. Manganin strips are used, as it has been found that the resistance of this metal changes less than other metals when heated. The strip construction further increases heat radiation and reduces temperature effects on the resistance value of the shunt. It must be remembered that the voltage drop across the shunt is governed by the current flowing in the circuit and the resistance of the shunt. Therefore, if the resistance of the shunt varied with temperature, a constant current would show up as a fluctuating one on the meter. The resistance of a manganin shunt does not vary with heat when properly designed for the load to be carried.

In most ammeters of the portable type the shunt is mounted within the instrument case in meters not reading over 25 amp. When the range is greater than this, a separate shunt to which the instrument is connected by leads is provided. Separate shunts are also provided for

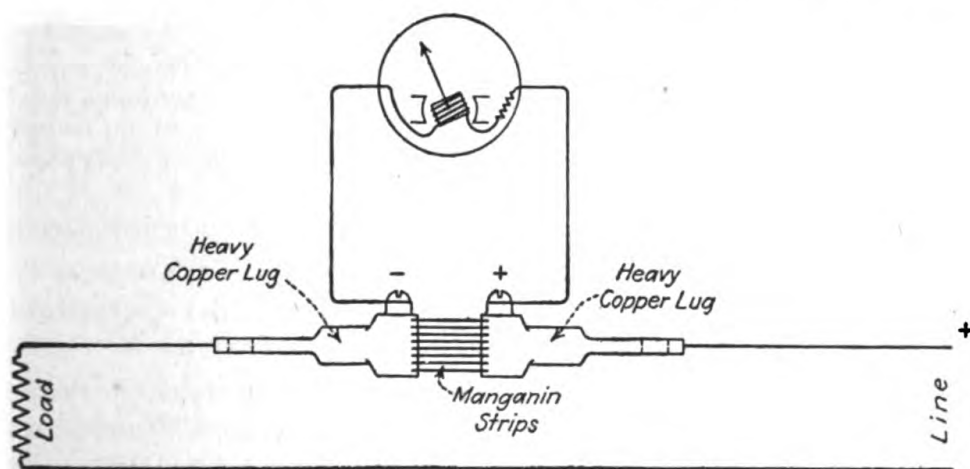


FIG. 6-28.—Shunt connected to ammeter.

high-grade laboratory instruments. It is becoming more and more the favorite practice to use separate shunts in connection with switchboard-type ammeters. When this is done the main currents do not have to be taken off the most convenient and best routes, it being only necessary to put a suitable shunt in series with the line at any point and run leads to it from an ammeter movement located in any convenient position on a switchboard or elsewhere. This practice also makes it possible to use one meter for various measurements, connecting it by a suitable rotary switch to the various shunts as required.

b. Figuring Shunt Values.—There are two factors which must be taken into consideration in the building of a shunt from the electrical-design standpoint. They are the resistance and the current-carrying capacity of the shunt. The resistance of the shunt is found by the equation $R = E/I$, where E equals the voltage necessary for a full-scale deflection, and I is the full-scale deflection in amperes desired on the meter when used in conjunction with the particular shunt to which the R value in ohms applies.

For example, if the voltage necessary to give full-scale deflection, as found by previous measurements, is 0.075 volt, and it is desired to have the ammeter read 30 amp., then the value of the shunt is $R = 0.075/30 = 0.0025$ ohm. If the resistance value of the shunt as thus found is inconvenient from a manufacturing standpoint, it is only necessary to change the series resistance used with the movement which would vary the E factor in the above equation. Hence by considering both the shunt value in ohms and the value of the series resistor a practical compromise may be found.

The power-carrying capacity of a shunt is found by the formula I^2R .

As the resistance of the meter must include the resistance of its leads, it is apparent that the length of these connecting leads cannot be materially changed after calibration of the meter without affecting its accuracy. The length of these leads is not critical, however, in an ammeter or milliammeter, and, under ordinary conditions, the accuracy of the meter is not affected by reasonable changes, provided extreme accuracy is not required.

c. A *current-limiting resistor* is used in series with the winding of the moving coil in nearly all ammeters. The value of this resistance varies with the type of meter. For switchboard purposes it is necessary to make the shunt loss low by developing only a small e.m.f. across it. It is necessary, therefore, to make the switchboard-ammeter movement sensitive to small potentials, and only a low resistance is used in series with the moving coil in this type of instrument. On the other hand, it is the practice to use a higher resistance in series with the moving coil of portable ammeters to reduce the temperature error in the movement, which is more important in portable service than reducing shunt loss.

d. The *direct-current milliammeter* is the typical ammeter movement described above with a higher resistance in its shunt and less in its series resistor.

The scale spacing on all direct-current ammeters and voltmeters of this type is uniform from zero to maximum.

It is conventional to connect ammeters and milliammeters in the positive side of the line as shown in Fig. 6-28. Notice the relation between the positive and negative markings on the meter and on the line. It is seen that while the positive side of the meter is connected to the positive side of the line direct, the negative side of the meter is connected to the negative side of the line through the load.

It is sometimes desirable to make a shunt for an ammeter or milliammeter already on hand. The problem then is to figure out the resistance of the shunt to be used. The ratio is expressed as follows:

$$\text{Resistance of shunt} = \frac{\text{proportion of } I \text{ through meter}}{\text{proportion of } I \text{ through shunt}} \times R \text{ of meter} \quad (5)$$

For example, suppose it is desired to make a 0 to 1 milliammeter read to 10 ma., the resistance of the meter being assumed to be 30 ohms.

Then,

$$R \text{ of shunt} = \frac{1}{10} \times 30 = 3.33 \text{ ohms}$$

The resistance of the meter in the above equation means the resistance measured across the terminal posts of the meter. See also Sec. 1.11.

6.30. Voltmeter for Alternating E.M.F.—These instruments indicate the r.m.s. value of the alternating e.m.f. For radio-power purposes two

types are most commonly used, namely, the *dynamometer type* and the *soft-iron-vane or repulsion type*.

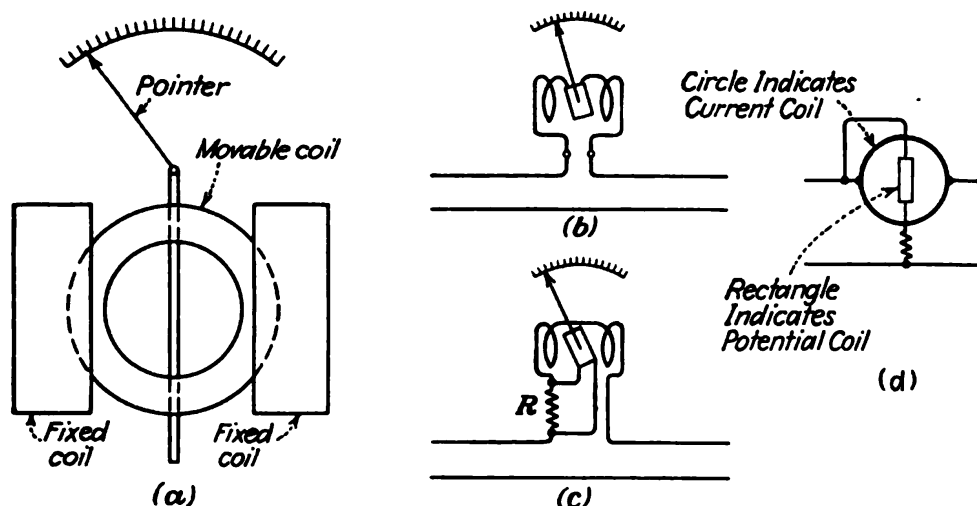


FIG. 6-29.—(a) Dynamometer movement; (b) series-connection method for small currents; (c) connection for voltage measurement; (d) a simple method of showing watt-meter connections.

The dynamometer type depends for its action on the reaction produced between a movable coil and a stationary coil, or between a movable coil mounted between two fixed coils. This movement is called the *dynamometer*, and the general scheme is illustrated in Fig. 6-29(a).

The soft-iron-vane-type meter depends for its action on the deflection which takes place between two pieces of soft iron bent concentrically and placed within a coil. The scheme is shown in Fig. 6-30. When the coil is energized, it magnetizes both pieces of iron in the same direction with the result that they repel one another resulting in a movement of the movable coil. Hence it is called a repulsion-type meter. The extent of the movement depends on the amount of excitation produced by the coil. A pointer is attached to the movable element which passes in front of a calibrated scale. As the reversals of magnetization due to the alternating current occur in the coil, the iron vanes are also reversed in polarity and the deflection factor remains constant regardless of polarity. It is possible, therefore, to use this type of movement on an alternating-current circuit.

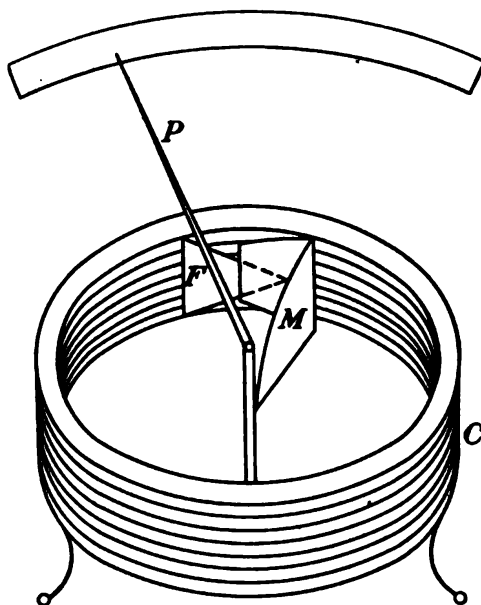


FIG. 6-30.—Iron-vane-type meter.

Both the dynamometer-type and the soft-iron-vane-type instruments are limited to use on commercial frequencies only and cannot be used to measure radio frequencies owing to the errors introduced when they are used on high frequencies.

The deflection of alternating-current instruments is non-uniform and tends to be proportional to the square of the current flowing through the meter. The indicating scale on these instruments is therefore of necessity non-uniform. For example, on an alternating-current instrument of the types just described the spacing between the scale units 3 and 4 is approximately one quarter the spacing between the units 15 and 16, assuming, of course, the instrument reads that high.

Another type of voltmeter called the *Thompson inclined-coil type* is very similar to the dynamometer type except that the stationary and movable coils are inclined, so that the plane of the fixed coils makes an angle of about 45 degrees with the shaft of the movable coil. This inclination of the coils tends to make the scale reading more uniform.

6.31. Ammeters for alternating-current circuits divide themselves into several types and classes ranging from the dynamometer and iron-vane types for commercial frequencies (usually not over 600 cycles) to the hot-wire and thermocouple types used for alternating currents of any frequency.

Ammeters utilizing the dynamometer movement (see Sec. 6.30) have the coils connected in series [Fig. 6-29(b)] when they are intended for current values up to 1 amp.; for values higher than 1 amp. the movable coil is connected across the series current-limiting resistor R , and the stationary windings are connected in series with the line and the resistor R . This method of connection is shown in Fig. 6-29(c) and is called the *wattmeter connection*.

Another type of ammeter is the Thompson inclined-coil type which is classed as an iron-vane-type meter but differs somewhat in construction from the Weston type of iron-vane meter (Fig. 6-30). The Thompson inclined-coil ammeter is similar to the Thompson inclined-coil voltmeter for alternating-current circuits, except that the moving coil has been replaced by an iron vane mounted at an angle to the shaft. When a current passes through the coil the vane tends to arrange itself parallel to the field set up by the coil.

6.32. Thermal Ammeters. *a. General Considerations.*—The thermocouple ammeter and the hot-wire ammeter are the two types of thermal meters used in radio. Certain considerations and characteristics belong to these meters as a class. It was soon found by early radio engineers that the ordinary moving-coil or iron-vane type of meter could not be used to measure radio-frequency currents accurately. Even if these meters were accurate at high frequencies, the inductance of their windings would change the oscillatory period or frequency of the radio circuit.

The hot-wire ammeter was then introduced for this work and permitted current measurements because it operated on any frequency; and because it had no winding it introduced no change into the radio circuit, the resistance of the platinum-silver wire being negligible.

It was then found that the accuracy of the moving-coil type of direct-current meter in conjunction with the e.m.f.-producing characteristic of the thermocouple unit could be used to measure radio-frequency currents. This resulted in the thermocouple ammeter which is now the type used almost entirely for radio-frequency-current measurement purposes.

In addition to its great accuracy and ruggedness, the thermocouple meter introduces no appreciable added inductance, capacity, or resistance into the circuit under measurement. It is for these reasons, in addition to its ability to measure all frequencies, that the thermocouple ammeter is used in radio-frequency circuits.

All thermal meters may be used on either direct or alternating current, and they are independent of frequency.

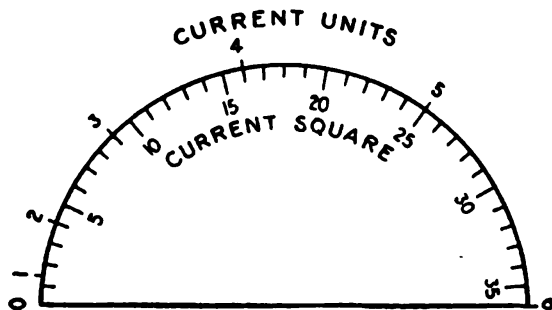


FIG. 6-31.—Meter scale.

b. Thermocouple Ammeters.—Certain metals, such as steel and constantan, bismuth and antimony, will produce a constant e.m.f. if brought under contact pressure at high temperatures. Such a combination of metals for this purpose is called a *thermocouple unit*. The heat which produces the e.m.f. is in turn produced at a rate which is proportional to the square of the current flowing through the thermocouple.

A direct-current millivoltmeter may be connected across the thermocouple to measure the e.m.f. produced in it. As the e.m.f. is proportional to the heating of the thermocouple, and as the heating is increased as the square of the current flowing through the thermocouple, then the e.m.f. must be increased as the square of the current flowing through the thermocouple. The millivoltmeter may, therefore, be calibrated in evenly spaced heat units across its scale, or it may be calibrated in amperes or milliamperes, or a combination scale may be used as shown in Fig. 6-31. If the scale is calibrated in evenly spaced units, the meter is called a *current-square* meter; if calibrated in current units it is simply an *ammeter* or *milliammeter*.

Current-square meters are valuable when small variations in current are to be noted, and this type of meter is useful on wavemeters and in other places where resonance and amount of deflection are more desired to be known than actual current values. It is evident that the actual current is the square root of the value in units indicated on the scale of the current-square meter.

The thermocouple ammeter will read either direct or alternating current of any frequency. Its chief use, however, is for measurements in radio-frequency circuits. As the thermocouple and the indicating meter are two separate and distinct devices, they may be located some distance apart and connected electrically if desired. Generally, the thermocouple unit is placed within the meter case unless the heat generated is so great as to make an outside location desirable, or the point where the measurement is to be made is remote from a convenient position for the meter.

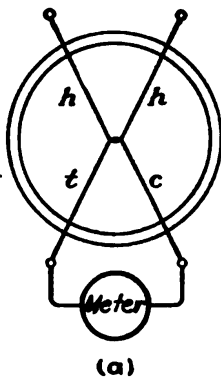


FIG. 6-32.—(a) Thermocouple and meter;
(b) correct symbol.

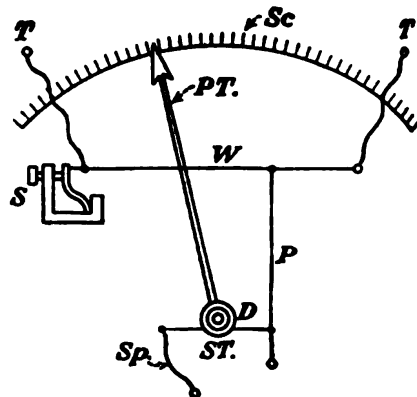
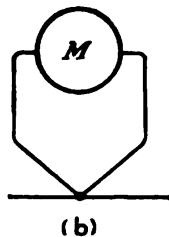


FIG. 6-33.—Hot-wire-ammeter mechanism.

The construction of the thermocouple unit is illustrated schematically in Fig. 6-32(a) where hh is the heater wire and tc are the two metals required for the thermocouple. The entire arrangement with terminals for the meter and the circuit forms the thermocouple unit. Particular attention is called to the correct method of drawing the symbol for the thermocouple ammeter which is properly shown in Fig. 6-32(b).

c. Hot-wire Ammeter.—Another type of thermal meter is the hot-wire ammeter which utilizes the expansion characteristic of a thin platinum-silver-alloy wire, when subjected to the heating effect of a current, to indicate current flow. The principle of the mechanism of this type of meter is shown in Fig. 6-33. The hot-wire ammeter is not very rugged owing to the fragility of the platinum-silver wire. In addition to this it is not very accurate and may lose its calibration. Also, owing to the thermal-expansion characteristic of the platinum-silver wire, a number of seconds must elapse after the application of the current before the meter will register. For these reasons and others, the hot-wire ammeter has been largely replaced by the thermocouple type of meter. The hot-wire ammeter does, however, still find some use in wavemeters for determining the resonance point and also for measuring the radiation, filament, and

late current in experimental transmitting stations where economy prohibits the use of a thermocouple meter.

The operation of the hot-wire instrument may be explained as follows: When the current passes through the platinum-silver wire W , it heats the wire, causing it to slacken; then the pointer PT , being mechanically connected to the wire by a silk thread $P-ST$ wound around a drum D , on the pointer axle, is propelled over the scale Sc in accordance with the amount of slackening of the hot wire. The scale may be either a current-square scale, or it may be calibrated directly in amperes. A screw S is provided to adjust the pointer to zero on the scale, and, as the wire is affected by room temperature, this is often necessary. A series resistance (multiplier) may be used to extend the range of a hot-wire ammeter and is connected in series with the meter and the line being measured. T and T' are terminals.

6.33. Wattmeters.—There are two types of wattmeters, the dynamometer type and the induction type. As the dynamometer type is most commonly used, this type will be described here. The wattmeter indicates the *rate* of energy expenditure or *power* being consumed in a circuit at any instant. The wattmeter should not be confused with the watt-hour meter which registers the total *amount* of energy consumed in a circuit. The ampere-hour meter, described in Sec. 18.33, is a type of watt-hour meter.

The dynamometer-type movement used in the wattmeter is the same as that used in the dynamometer-type voltmeter, described previously and which is illustrated in Fig. 6-29(a). The fixed and movable coils are connected in accordance with the wattmeter connection shown in (d) of the same figure.

If an alternating-current circuit contains resistance only, it has unity power factor, and the power expended in watts is found by the simple equation $W = E \times I$, but, if the circuit contains inductance or capacity (or the equivalent), the power factor must be taken into consideration. The equation then becomes $W = E \times I \times \cos \theta$. The wattmeter automatically takes these three factors into account, and the value indicated by the pointer on the meter scale is a true power reading.

In representing the wattmeter (or a dynamometer-type meter in any other use) the current-limiting resistor in series with the shunt circuit should always be shown. The simplest method of showing the wattmeter is shown in Fig. 6-29(d), wherein the series (current) coils are represented as a circle and the shunt (voltage) coil by a rectangle.

6.34. Frequency Indicators.—The preferred term *frequency indicator* rather than *frequency meter* is used here to differentiate between the instrument used on power lines to measure the frequency of alternating e.m.fs. at power frequencies and the conventional wavemeter circuit commonly known as a *frequency meter* and used to measure the frequency of radio-frequency currents.

The frequency indicator provides a scale and a movable pointer from which may be read directly the frequency of the alternating-current

circuit to which it is connected. There are other types, such as the vibrating-reed type, which are built on a different principle but which need not be considered here. The frequency indicator met with in everyday practice looks like a voltmeter, ammeter, or any other conventional electrical indicating instrument.

A common type of frequency indicator is the Westinghouse induction type, the general scheme of which is shown in Fig. 6-34. Its construction and operation are explained as follows: Two coils A and B act on the rotatable disk G tending to turn it in opposite directions when a current flows through the coils. A non-inductive resistance R is connected in series with the A coil, and an inductive reactance X_L is connected in series with the other coil, B . The amount of current flowing in the coil B is controlled by the impedance of the reactance X_L which varies with

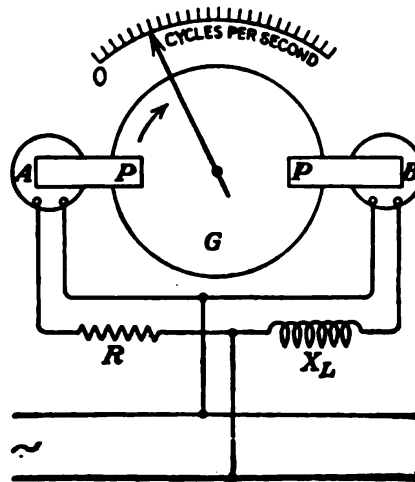


FIG. 6-34.—Induction-type frequency indicator (Westinghouse).

frequency. Hence, the effect of the two coils on the disk is unbalanced, and the disk tends to orient itself to a definite position in accordance with the frequency of the applied alternating current. PP are the poles of the field magnet.

6.35. The Ohmmeter.—The simplest type of direct-reading ohmmeter and the one generally used for radio-circuit testing and resistance measuring consists of a direct-current milliammeter, a known resistance (R_c), and a dry cell or cells for supplying e.m.f., arranged in a circuit as shown in Fig. 6-35(a). The unknown resistance, or the circuit, the continuity of which is to be tested, is connected across the terminals XY . With XY short-circuited, the resistor R_c is of such value that the applied e.m.f. causes a full-scale deflection on the meter. It is evident then that any resistance introduced across XY will cause the meter to read less than full scale, the amount less depending on the amount of resistance introduced at XY . The ohmmeter, therefore, reads backward, that is, zero ohm is at the right-hand end of the scale.

A typical ohmmeter scale is shown in Fig. 6-35(b). Using this scale in conjunction with a Weston type 301, 0 to 1 milliammeter, resistances up to 50,000 ohms may be read directly on the scale when the applied e.m.f. is 1.5 volts and the value of R_c is 1,500 ohms. The range of the meter may be extended by increasing the value of R_c . The factor by which R_c is multiplied then becomes the multiplying factor for the scale. For example, if R_c is increased 15 times ($1,500 \times 15$) to 22,500 ohms, then the scale indication must be multiplied by 15, giving a maximum range of ($15 \times 50,000$) 750,000 ohms. The battery voltage must always be great enough to operate the meter. Hence, when very high resistances

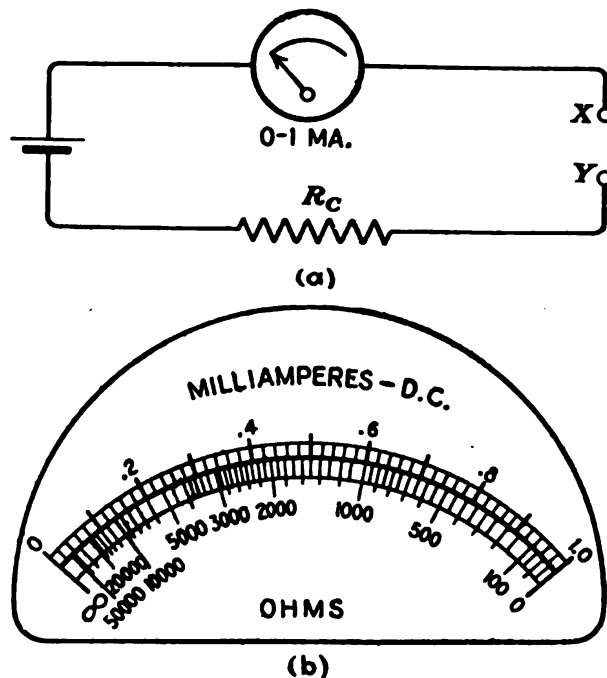


FIG. 6-35.—(a) Ohmmeter circuit; (b) ohmmeter scale.

are to be measured, the battery e.m.f. must be increased proportionately. For certain radio-circuit tests an ohmmeter is indispensable.

Another simple and very accurate method for determining unknown resistance values is the voltmeter method. If the resistance of the voltmeter is known,¹ the value of any unknown resistance may be determined by the following procedure:

Let it be assumed that the voltmeter has a resistance of 100,000 ohms and a full-scale reading of 150 volts. That is, if the voltmeter is connected across an e.m.f. of 150 volts, the meter will give a full-scale deflection of 150 volts. Now, if an unknown resistance is connected in series with the instrument under these conditions, the reading on the voltmeter scale will obviously indicate less than 150 volts, owing to the

¹ The resistance of any voltmeter in question may be obtained from the manufacturer or by measurement with a standard ohmmeter.

IR drop across the unknown resistance. If, therefore, the insertion of the unknown resistance drops the scale reading to, say, 125 volts, then the value of the unknown resistance may be readily computed from the expression

$$R_x = R_m \times \left(\frac{E_1}{E_2} - 1 \right) \text{ ohms} \quad (6)$$

or in this instance,

$$R_x = 100,000 \times \left(\frac{150}{125} - 1 \right) = 20,000\omega$$

This method is extremely simple and accurate, particularly where high values of unknown resistances are to be determined.

CHAPTER 7

ANTENNAS AND WAVE PROPAGATION

In order to radiate electromagnetic and electrostatic energy into space, it is necessary to obtain a circuit which will not confine the useful fields to the immediate vicinity of the coil and condenser constituting the closed oscillatory circuit, where it would be absorbed. It is found, on the other hand, that an *open oscillatory circuit*, such as capacitive or resistive antennas, which have their inductance and/or capacity distributed over a large area, will radiate a large part of the energy flowing in them. The converse is not necessarily true of receiving antennas as we shall see later.

I. ELEMENTS OF RADIATION

7.1. The Radiation Field.—In this section the way in which currents and voltages in the antenna are capable of producing disturbances in the ether or medium carrying the wave motion will be considered. It is understood that the current-amplitude curves (Fig. 7-13) simply show the relative quantity of electrons passing a given point in a specified period of time. This electron flow produces a magnetic field around the conductor, the same as in low-frequency power circuits. In addition to the magnetic field there is also an electric or electrostatic field which is due to the potential differences of the ends of the antenna. In Fig. 7-1 are shown the magnetic lines of force and also the electrostatic lines which are always at right angles to them. This is sometimes called *space quadrature*. The wave is said to be *polarized* in the direction taken by its electrostatic field. Thus, we may have vertical or horizontal polarization.

To define what this field actually consists of, we must first give some explanation of the material from which it is built; in other words, we must define *ether*. This medium is generally considered to consist of the resultant of all electric fields at the position in question. Then the electric field and magnetic fields are strained conditions of this "ether."

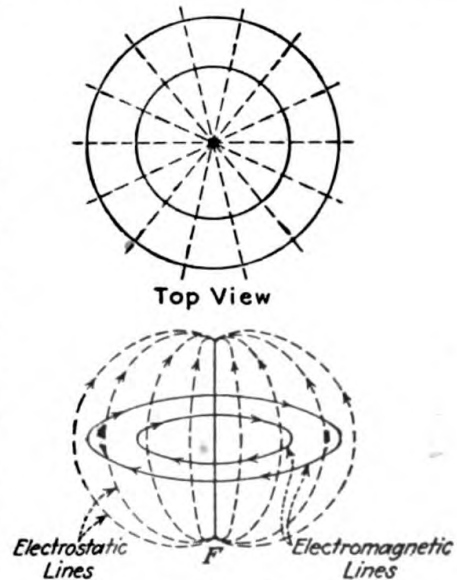


FIG. 7-1.—Electric and magnetic field distribution around a vertical antenna.

From another viewpoint, ether is the medium that conveys light and electromagnetic energy through space, interpenetrating all matter and being universally diffused through it. As the current flow increases in the antenna in one direction, the magnetic and electric fields are moving out in all directions from the conductor with the velocity of light; but, as the current flow in the conductor begins to decrease, the field or strain near to the conductor begins to collapse or move in toward the conductor. However, it takes an appreciable time for the electromagnetic field to change its direction of motion; it takes time for this new force to move out and affect the field to the full extent of the first disturbance, and in this period of time the first wave has progressed farther out. Because of this condition, most of the energy is not returned to the antenna circuit as it would be in a tank circuit or in a parallel-tuned closed oscillatory circuit.

The distance between successive points of the same polarity and phase value in a wave train is called the *wave length* of the wave. The usual symbol is λ (the Greek letter lambda). Since the number of these waves which are sent out depend on the frequency or period of vibration of the oscillator or radio transmitter, it follows that the velocity of wave travel will equal the wave length of one disturbance multiplied by the frequency of oscillation. Thus we write

$$V(\text{meters per second}) = \lambda f \quad (1)$$

In a given medium the length of a wave (radio, light, or water) will be of a fixed value, the frequency of course remaining the same. This means that if a radio wave passes through a medium other than air, it will have a different wave length and a different velocity while it is traveling in the other material.

As we mentioned above, the electrostatic and electromagnetic fields are interlinked and travel through space together; but in cross section they would be found to be 90 degrees displaced in quadrature. It can be shown that these two fields are interdependent. If energy is taken from one field, it is balanced or replaced from the other so that the energy content over a cycle is always equal.

7.2. Sky and Ground Waves.—The radiated wave is considered to travel by two paths toward the receiving site. The first, and for broadcast reception the most important, is the ground wave, or that part of the energy which travels along the surface of the earth. The other path, which is responsible for the success of short-wave circuits, depends on reflection from one or more of the ionized layers which are considered to exist at great heights in the atmosphere. These two propagation paths cannot be considered entirely independent, as the ground wave is reinforced by diffusion from low-angle radiation slightly above the ground wave, which is entirely different from any Heaviside layer reflection.

At night it is also found that there is a *sky wave* or reflected wave to contend with, on broadcast frequencies, as well as the ground wave, making the problem of estimating the signal strength more complex.

We shall first consider the ground wave during daylight conditions. As stated above, this will eliminate consideration of Heaviside layer reflections, although there are some evidences of reflection at great distances.

It is well known that reception over salt water is better than over dry, sandy ground, the reason being, of course, that there is less attenuation of the ground wave when the path is over a good conductor. However, the ground-wave field strength can never be as great as would be indicated by the inverse-distance curve. The difference between the actual signal received and the inverse-distance curve will be due to this attenuation of the signal by the ground or water over which it passes.

At ultra-high frequencies (above 30 megacycles), signals are not returned to earth from the Heaviside layer although there may be a certain amount of bending in the lower atmosphere and occasional reflection from an unusually low, heavily ionized portion of the ionosphere. Every effort is made to obtain a clear line-of-sight path between the transmitter and the receiver. In addition to the direct ray between transmitter and receiver, the signal also is reflected from the ground and from buildings, hills, and any other obstructions.

The wave is almost completely reversed in phase upon reflection and tends to cancel the direct signal except that the path lengths are different, owing to the reflected wave taking a longer route than the direct wave. Because of this, the two waves do not arrive quite out of phase and appreciable signal strength remains. If either the transmitter or receiver antenna is raised above the reflecting surface, the direct-signal path length becomes greater and more signal is received.

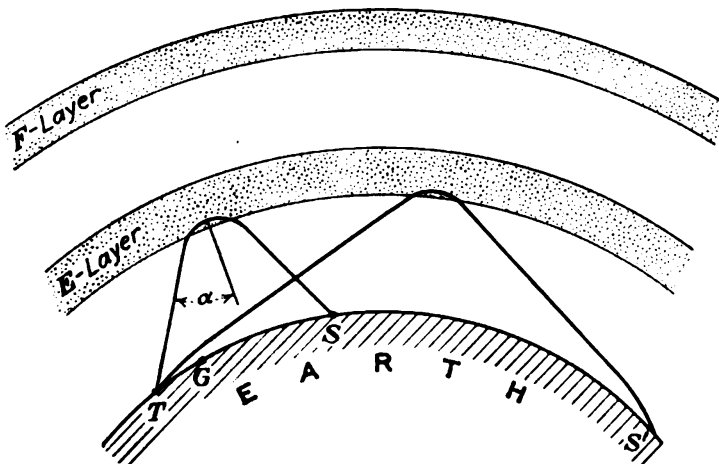


FIG. 7-2.—Reflecting layers and signal paths.

7.3. Skip Distance.—The first point at which a reflected wave reaches the surface of the earth would be at point *S*, Fig. 7-2. Since the ground wave travels only a short distance such as *TG*, it can be seen that the distance from *G* to *S* will have no signal. The limit to the low-angle

radiation is the lowest critical angle which can be propagated without absorption by buildings, trees, and other obstructions. Then the area from S to S' is completely covered by the reflected waves. In general, it is found that the critical angle α may be smaller for low frequencies without decreasing reflection from the ionized layers. This means that a lower frequency should be used for short- than for long-distance transmissions.

It is naturally to be expected, and is approximately true, that the greatest ionization occurs at noon when the ultraviolet rays reaching the earth are most intense. At this time, the reflecting layers, which consist of ultraviolet radiations, are nearer the earth, resulting in a shortening of the skip distance GS . Recall again now the fact that, in general, a small critical angle is characteristic of a low frequency and a large critical angle is characteristic of a high frequency. It is seen then that a higher frequency can be used in the daytime, when the layer is low, than at night, when the layer is high, without affecting the reflection of the wave to the earth. With a given angle, it is seen, that as the reflecting layer is raised, the skip distance increases. Hence, if a high-angle, high-frequency wave is used at night, the reflected wave will pass far beyond the earth owing to the greater height of the reflecting layers. By keeping the angles shown in Fig. 7-2 fixed, it is easily seen how the skip distance varies with a change in the height of the reflecting layer or layers. Average experimental values for the skip distance found in summer and winter for day and night transmissions at two frequencies near the opposite ends of the high-frequency spectrum are given in the following table:

TABLE VIIA.—APPROXIMATE SKIP DISTANCES

Frequency, kilocycles	Approximate skip distance, miles			
	Summer		Winter	
	Day	Night	Day	Night
6,000	90	300	150	750
15,000	500	2,800	1,000	10,000

In general, then, the best frequency to use is the one which gives the desired reflection. Therefore, if the distance between the transmitter and receiver is known, and the frequency which has a skip distance up to the point is also known, it is only necessary to decrease this frequency about 20 per cent to obtain the optimum frequency. This is an approximate method. Some comprehensive charts on propagation over the north Atlantic Ocean have been prepared.¹ Another paper² shows

¹ BURROWS, C. R., *Proc. I. R. E.*, September, 1931, p. 1634.

² PRESCOTT, M. L., *Proc. I.R.E.*, November, 1930, p. 1797.

propagation characteristics in all directions from Schenectady, N.Y., and is very valuable for anyone choosing frequencies for a radio circuit. It must not be assumed, however, that from year to year conditions will stay the same, as there have been pronounced variations in certain years, probably due to sun spots or magnetic storms. A chart showing the approximate relation of optimum frequency to distance in short-wave transmission is shown in Fig. 7-3.

7.4. Field Intensity.—The inverse-distance curve or equation will in any case be found to give the maximum signal which it is possible to

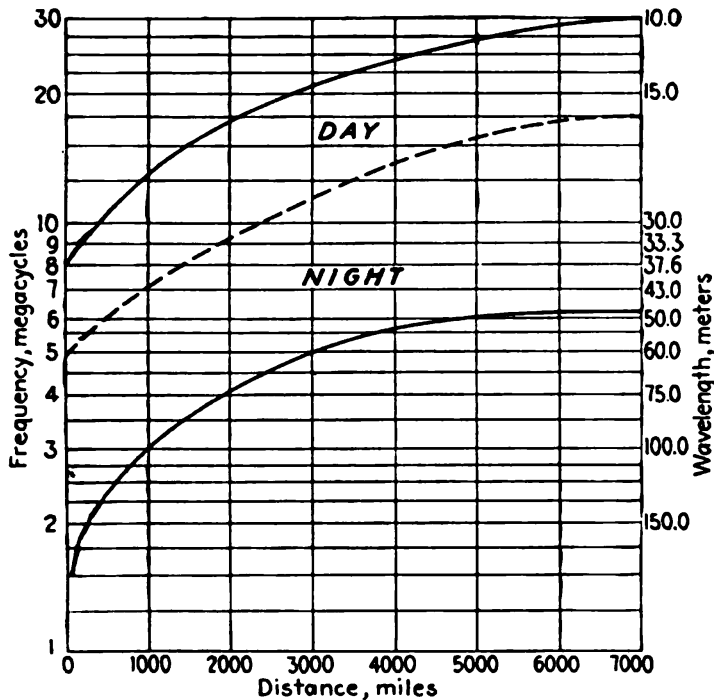


FIG. 7-3.—Skip-distance curves.

receive, as it provides only for the spreading out of the wave and does not make any allowance for attenuations. There will frequently be signals of as high an intensity as this inverse-distance curve indicates, owing to reflections from the ionized layers of waves which are not attenuated by the ground; so, the equation has value in estimating the maximum signal possible in a given condition. This equation may be shown to be quite accurate for short distances where the curvature of the earth does not affect the results. The equation, when measurements are made in miles, is as follows:

$$\xi = \sqrt{P_{\text{watts}}} \frac{5.87 \times 10^3}{D_{\text{miles}}} \quad (2)$$

where D_{miles} = the distance in miles from transmitter to receiver.

ξ = the received signal in microvolts per meter.

P_{watts} = the power in watts radiated by the antenna.

Field-strength measurements are generally measured in microvolts ($\mu\text{v}/\text{m}.$) or millivolts per meter ($\text{mv}/\text{m}.$) at different points from the radiating system to determine the distribution and efficiency of the field pattern. For example, let us assume that a potential difference of 100 volts is developed between the antenna system and the ground owing to excitation from the transmitter. As a result an electric field will be developed owing to the strained area between these points. Now let us assume the antenna to have a vertical height of 200 ft., or approximately 61 meters (1 ft. = 0.3048 meter). Since the potential of 100 volts developed across these two points is separated by 61 meters, the strength of the field would be 1.639 volts per meter. This is obtained by the reasoning that if a potential difference between two charged bodies is 100 volts for a distance of 1 meter, the potential difference, if the two charged bodies are moved apart to a distance of 2 meters, will be 50 volts per meter. Thus, in this example the potential difference of 100 volts is distributed in 61 meters which, therefore, means that 1.639 volts are developed for each meter. Hence it may be seen that the closer the relation of the bodies to each other, the greater will be the field strength per meter; and the farther apart the two bodies, the lower the field strength in volts per meter. Consequently, as the distance from the point of measurement to the radiation system increases, the field strength per meter decreases. The strengths of the fields, therefore, at remote points from the radiating system may decrease to such small values that they are measured in millivolts or microvolts per meter.

There have been a large number of field-strength surveys made, and many of these surveys are checks on the basic formulas proposed by Sommerfeld in 1909. Using this formula P. P. Eckersley¹ has worked out a number of curves of field strength in millivolts per meter. His measurements show attenuation factors ranging from 10 to 11 c.g.s. units to 0.75×10^{-14} c.g.s. units, depending on the dampness of the ground and on its hilly or mountainous character, the mountainous country having very high attenuation.

It may be well to mention what effects are generally caused by some of the disturbing elements to propagation which were mentioned above. It is thought that a sun spot or a flash of ultraviolet light from the sun has an effect on the magnetic activity on the earth, and, owing to this disturbance or to the effect of the ultraviolet radiation on the ionized Heaviside layer, the propagation of radio waves is affected. Nevertheless, it is very noticeable on short-wave radio circuits that, when there are aurora borealis displays, there is a pronounced drop in signal strength on east-west circuits, especially those operating in the northern sections. The effect is not nearly so pronounced on north-south circuits. The effect does not seem so pronounced on broadcast frequencies; and on long waves there is sometimes an increase of signal reported in the daytime. On short waves below 75 meters, this effect is so pronounced that many short-wave circuits become entirely inoperative during these magnetic storms. It is said that one of the leading communication companies in this country keeps its old long-wave transmitters very busy during these periods.

¹*Proc. I.R.E.*, July, 1930, p. 1170.

Other losses which are considered to have some effect on radio waves are eddy currents and magnetic hysteresis. There has been noticed pronounced weakening of broadcast signals measured in a test car on the far side of a downtown New York section. This seemed without doubt due to absorption or screening by the tall steel buildings in the propagation path. Dielectric losses are often due to trees, buildings, or wooden masts in the field of the antenna, especially when the mast is not dry and painted. Ionization of the air probably has an attenuating effect. Thus it is considered that the excessive ionization during daylight is responsible for the lack of Heaviside layer reflection at broadcast frequencies during the day.

At night the conditions are entirely different. The ground wave is present the same as before, but in addition there is a reflected wave at broadcast frequencies which generally has an amplitude comparable to that of the ground wave at a distance which varies from about 35 to 60 or 70 miles depending on which end of the broadcast-frequency spectrum is involved, the antenna design, and the conductivity of the ground. At this circle around the transmitter site there will be pronounced fading at times, owing to the fact that the reflected ray will be out of phase with the ground wave, and the fields from the two sources will cancel. Because of this fading and poor reception, at points near and beyond this distance, it is becoming common practice to estimate the service area of a broadcast station as an area well within this circle. It can be seen that no increase in power will change the position of this *fading circle* because both the sky wave and ground wave are increased in intensity in the same degree. The amount of power to use is then determined by the signal strength necessary within this area. This, however, may be as high as 50 kw. or more. It can be seen that the lower frequencies of the broadcast band have a pronounced advantage from this standpoint, since the distance at which fading will start, will be at a greater distance from the transmitter. This means that a proportionately greater *service area* will be found for low-frequency stations. The signal beyond the service area depends almost entirely on the sky wave and will fade at times, the same as short-wave signals do, because of changes in the Heaviside layer. However, it may often be considered as a fairly good signal by the average listener when stronger and more constant signals are not present.

The field strength from a half-wave type of radiator is approximately

$$\xi = \frac{88 \sqrt{w} ah}{\lambda r^2} \quad \text{volts per meter} \quad (3)$$

where w = watts radiated.

a = height of receiving antenna above ground in meters.

h = height of transmitting antenna above ground in meters.

λ = wave length in meters.

r = distance between transmitter and receiver in meters.

The distance to the horizon of either the transmitter or receiver (for line-of-sight transmission) is

$$D = 1.22 \sqrt{H} \quad \text{miles}$$

where H = height above average ground level in feet.

The transmitter horizon and the receiver horizon added together give the maximum line-of-sight distance. Beyond the line of sight, signals can still be readily received if sufficient power is available owing to the

diffraction of the signal in passing over the curved surface of the earth. The attenuation over to the line-of-sight distance varies approximately as the square of the distance. Beyond the line-of-sight distance, the signal drops off more rapidly (inversely as the 3.6 power of the distance for 40 megacycles and as the fifth power of the distance for 100 megacycles).

The field strength calculated from formula (4) may be at variance with the observed field by as much as 10 to 1 if unusual circumstances such as intervening buildings or hills exist.

Equation (3) may be converted into more practical form as

$$\xi = \frac{0.01052 \sqrt{w} ahf}{r^2} \quad \text{microvolts per meter} \quad (4)$$

where f is in megacycles.

From the above, it follows that short-wave antennas must be designed to deliver a maximum field at 5 to 50 degrees above the horizon to take advantage of reflection from the Heaviside layer, whereas ultra-high-frequency antennas must be designed to deliver a maximum field parallel to the earth's surface.

High-frequency installations are used for long-distance transmission, such as international broadcasting, international telephony and telegraphy, moderate- and long-distance communication circuits, and where antenna space is limited as in aircraft transmission and other relatively small mobile stations.

Ultra-high-frequency installations are used for television and frequency-modulation broadcasting, aircraft landing systems, short-range communication circuits and mobile stations, and for special purposes such as aircraft radio altimeters and locators.

II. ANTENNA SYSTEMS

7.5. Short-wave Antennas. *a. General Considerations.*—A wire in space carrying high-frequency alternating current constitutes an antenna. Radiation from this antenna takes place by virtue of the expanding magnetic and electrostatic fields accompanying the charges flowing in the wire. Resonance in the wire and the method of feeding have no particular significance in the process of radiation. Resonance in the antenna system happens to be a convenient method of building up high currents, and, therefore, practically all antennas are resonated, usually by making them a half-wave long or some multiple thereof. A feed system is a method for introducing energy into the antenna and does not affect the operation of the antenna proper. Thus, an antenna should operate in the same manner whether it is fed on the end, in the center, through open wire feeders, concentric feeders, tuned lines, untuned lines, or any one of a dozen sys-

tems. An exception to this would be if the feed system were radiating and was therefore, equivalent to a portion of the antenna.

b. Vertical Antennas.—Short-wave vertical antennas may be used although these are not so common as horizontal antennas. Certain advantages may be obtained from a vertical antenna if a ground plane of high conductivity is available such as a site in a salt marsh or at sea. In this case, it is possible to obtain lower angles of radiation coupled with non-directional or horizontal directivity properties. Low-angle radiation would be advantageous for very long-range communication.

c. Horizontal Half-wave Antennas.—The basic short-wave antenna is the half-wave antenna. Its physical length is just short of a half wave length because, owing to radiation losses, the radio-frequency energy travels on the wire with a little less speed than the velocity of light. The exact length of wire depends to some extent on the diameter of the wire

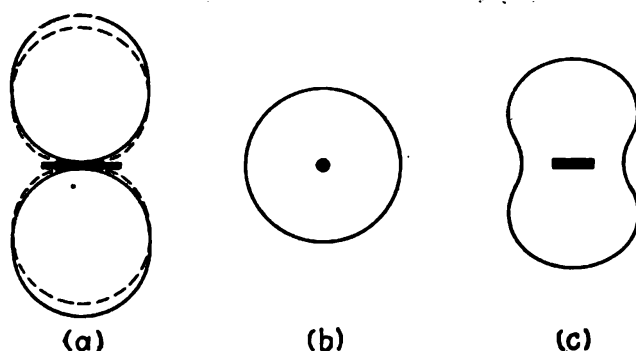


FIG. 7-4.—Horizontal half-wave antenna patterns.

(this effect is appreciable at the ultra-high frequencies but negligible up to 30 megacycles or so) and on the proximity of the ground and other near-by radiators. A length of 95 per cent of a half wave length is about right for average installations.

If the antenna is horizontal, the radiation pattern looking down on the antenna will be a *figure of eight*. The lobes of the figure of eight will be somewhat narrower than perfect circles as shown by the comparison with the dotted circles in diagram (a), Fig. 7-4. Looking at the end of the antenna, the free space pattern will be a circle as in diagram (b). These patterns are altered by the presence of the ground, since reflections from the ground add to the direct radiation to produce patterns as shown in Fig. 7-5 for various heights above the ground. Since the ground is not a perfect reflector, the nulls are moderated and the vertical directivity is less marked than pictured here.

Each of the lobes shown has a particular horizontal pattern depending upon its angle above the horizon. In practice, a horizontal antenna does not exhibit marked directivity as shown in Fig. 7-4(a), because useful radiation takes place at some definite vertical angle and the nulls fill in at higher angles above the horizon as in diagram (c), same figure.

7.6. Directive Antennas. a. Forms and Patterns.—It is sometimes desirable to control the distribution of the radiated energy. For example, a broadcast station may want to direct its energy toward centers of high population or to reduce its energy in other localities to prevent interference with other broadcast stations. Also, because much point-to-point communication is done in crowded frequency channels and under conditions that make secrecy desirable, a definite control of the radiated energy is often necessary. In addition to the reasons just

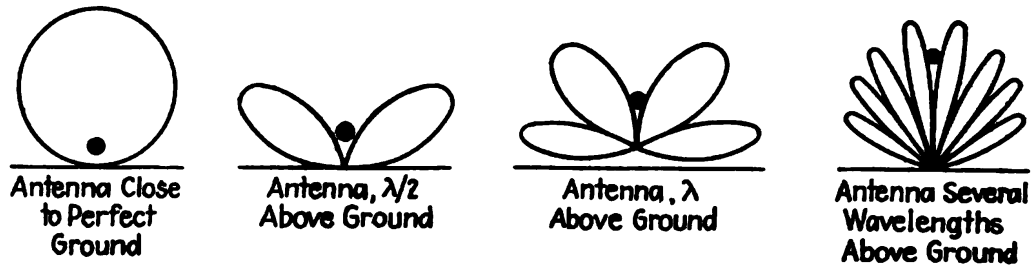


FIG. 7-5.—Radiation lobes.

stated, the field strength per dollar of operating expense can be greatly increased by the proper control and concentration of the radiated energy. Such control and concentration can be achieved by the use of *directional radiating systems* or *arrays*.

Directive arrays take on three general forms:

- a. Groups of half-wave radiators.
- b. Groups of half-wave radiators where some are excited by the induction fields of the main radiators instead of directly, acting then as parasitic reflectors and directors.
- c. Long-wire antennas, either resonant or terminated.

Half-wave radiators may be grouped in three directions: (1) at right angles to the direction of transmission, (2) both horizontally and ver-

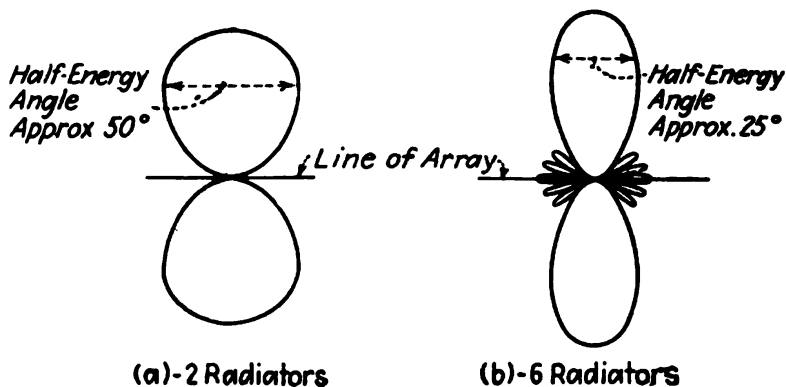


FIG. 7-6.—Broadside array lobes.

tically, and (3) along the line of transmission. The first is known as the *broadside array*. If the radiators are stacked both horizontally and vertically, it is often called a *curtain*. If the radiators are arranged along the line of transmission, the array is termed an *end-fire array*.

The pattern of a broadside array is shown in Fig. 7-6 for various numbers of radiators spaced $\lambda/2$ apart and fed with equal inphase currents. The small lobes, diagram (b), which appear in addition to the main lobe, may be eliminated at some expense to sharpness of the main beam by proper proportioning of the current distribution in the array.

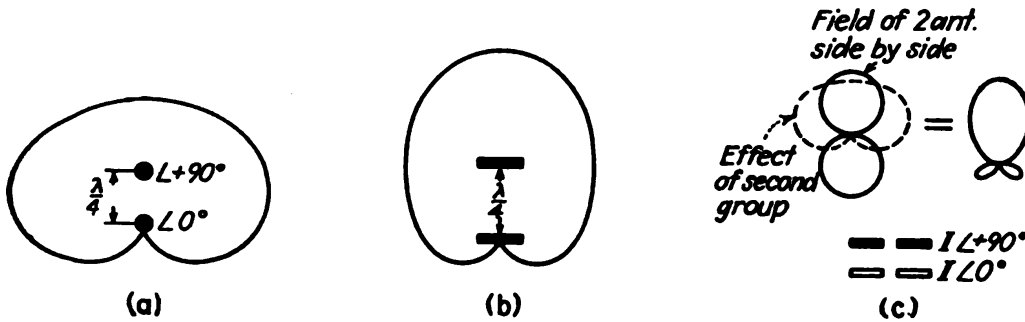


FIG. 7-7.—Horizontal- and vertical-phase patterns.

A pair of antennas spaced $\lambda/4$ apart and fed with currents 90 degrees out of phase will exhibit a cardioid pattern as illustrated in diagram (a), Fig. 7-7. If these antennas are horizontal, the pattern will be multiplied by the directivity of the horizontal antenna as shown in diagram (b).



FIG. 7-8.—Parasitic director and reflector.

Similarly, if horizontal groups of antennas are used as in diagram (c), the cardioid of diagram (a) will be multiplied by the directivity of the horizontal groups. This principle can be extended to a large number of radiators. Thus, in transoceanic telephony a curtain of half-wave radiators is often backed up by a second curtain fed in quadrature to the first curtain.

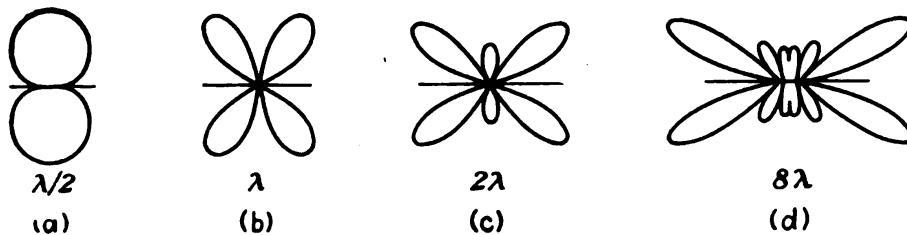
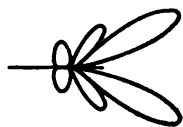


FIG. 7-9.—Long-wire lobes.

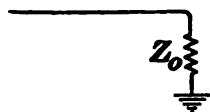
If any antenna has placed close to it another parallel radiator, commonly known as a parasitic director or reflector, considerable directivity and power gain can be achieved. This is shown in Fig. 7-8.

The director is made shorter than the antenna so that it has a capacitive reactance and the currents induced in it by the antenna will lead the antenna current. The reflector is made longer than $\lambda/2$ in order to

obtain an inductive reactance and the lagging current desired. For maximum forward gain, the director is placed approximately 0.1λ in front of the driven antenna and the reflector about 0.125λ behind it.



(a)
Half Pattern
of Fig. 9(d)

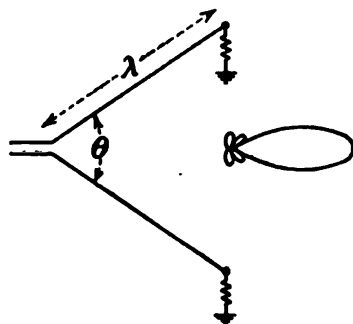


(b)
Terminated 8λ

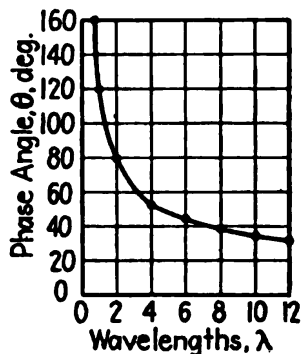
When an antenna is tuned properly for transmitting, it is also tuned properly for receiving and exhibits the same directional properties in either case.

FIG. 7-10.—Properly terminated characteristic of a long-wire antenna.

b. Long Wire Antennas.—A very long wire exhibits marked directional characteristics as shown in Fig. 7-9. The longer the wire, the closer the main lobe lies to the axis of the wire. If the wire is terminated at the far end in its surge impedance so that no reflections occur, half the pattern disappears as shown in diagram (a), Fig. 7-10.



(a)



(b)

FIG. 7-11.—Characteristics of a V beam-antenna.

Two wires may be combined at the proper angle to cancel one of these lobes and reinforce the other, as in diagram (a), Fig. 7-11. Such an arrangement is known as the V beam. If it is left unterminated, radiation will also take place in the backward direction, but with no

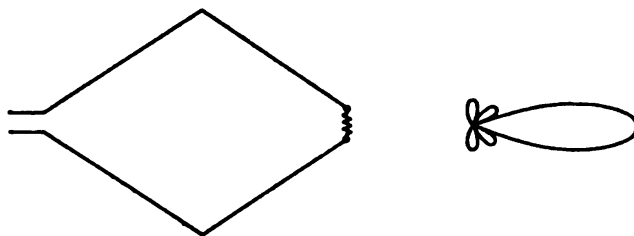


FIG. 7-12.—Characteristics of a diamond or rhombic antenna.

significant loss in power, since the energy in this lobe would normally be dissipated in the termination resistor.

A *rhombic* or *diamond antenna* is an extension of the V, so the curve shown in (b) of Fig. 7-11 applies also to this type of antenna, which is illustrated in Fig. 7-12.

7.7. Feeding the Antenna.—One of the earliest methods of applying energy to a single half-wave antenna was to fasten it to one wire of a two-wire transmission line as shown in diagram (a), Fig. 7-13.

This was known as a *Zepp* feeder. The line is not only badly mismatched, but is unbalanced as well, so that considerable radiation from the feeder occurs.

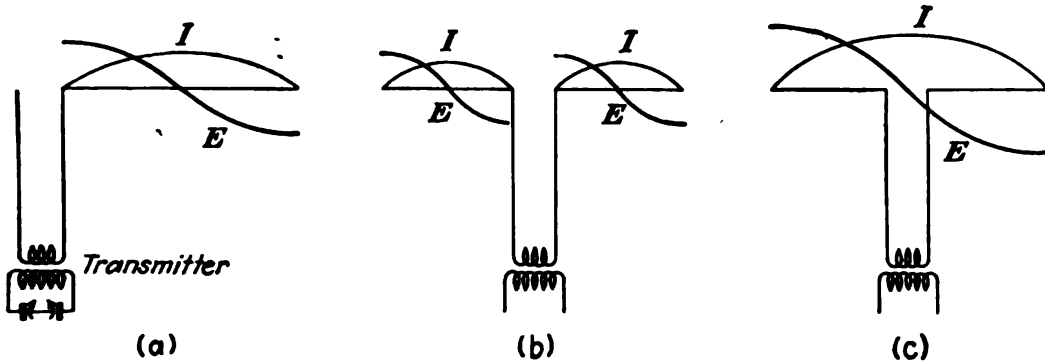


FIG. 7-13.—Zepp feeder arrangements: (a) and (b) voltage feeds; (c) current feed.

Using two antennas instead of one in a balanced arrangement as in diagram (b) materially reduces the feed-system radiation since the line is then balanced. The line still looks into several thousand ohms at the antenna, whereas most two-wire lines have a surge impedance of 250 to 1,000 ohms. Feeding a single antenna results in about the same degree of impedance mismatch, diagram (c), since here the feeder looks into about 70 ohms in the absence of other radiators nearby. In this case,

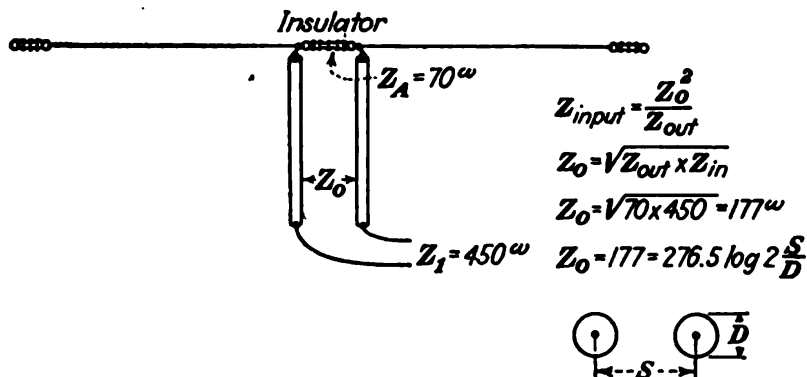


FIG. 7-14.—A half-wave antenna equipped with a quarter-wave feeder.

a match can be achieved by a quarter-wave section of line having a characteristic impedance which is a mean between the antenna input resistance and the characteristic impedance of the main feed line. Such a device would be in the form of a relatively large-diameter stiff copper tube connected as illustrated, Fig. 7-14. One method of matching the antenna to the line is to spread the line out at the end and tap onto the antenna as shown in Fig. 7-15(a).

The antenna looks like a parallel tuned circuit having a Q of about nine. If the antenna is resonant, tapping across a portion of it will result in a load that is nearly resistive, and a section can be found that will match the 600-ohm open-wire line.

If the spacing between a pair of transmission lines is made very large, the impedance of the line approaches a value of 1,200 ohms or so. If one wire is removed altogether, the remaining wire has a surge impedance of approximately 600 ohms to ground. It can be attached to the antenna, diagram (b), (Fig. 7-15) at a point that will terminate it correctly, and a single-wire feed system results. The feeder radiates, whether it is terminated or not, because it is a wire in space carrying current and this constitutes an antenna. However, the radiation is fairly small if the feeder does not exceed one-half wave length.

The two-wire line of Fig. 7-13(b) can be matched by picking a point on the line where the reciprocal of the conductance is equal to the surge

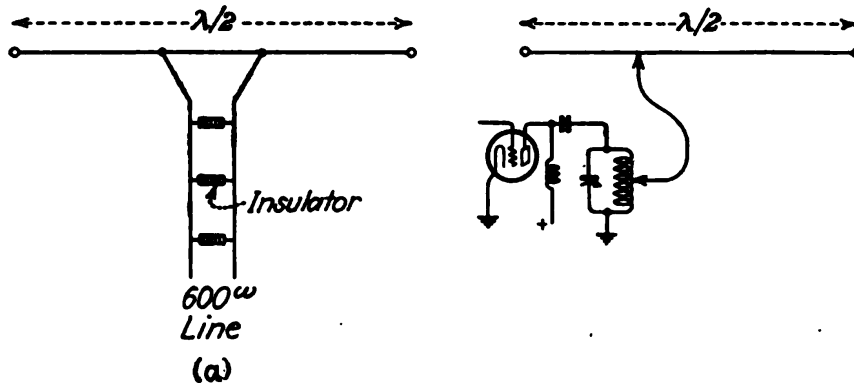


FIG. 7-15.—Simple antenna impedance-matching arrangements.

impedance of the line and then tuning out the reactance by shunting a section of transmission line of proper length across the feeder.

If the line is properly terminated, the transmitter load will be a pure resistance equal to the characteristic impedance of the line. If the line is misterminated, the load on the transmitter will depend on the frequency and the length of line involved. In the average case, the load will be reactive and must be tuned out by coils or condenser in series with the line or across the line. A combination of both can be made to transform any complex value of line impedance to a resistance of any desired value for properly loading the transmitter. The circuits illustrated in Fig. 7-16 (a) and (b) are known as *pi* networks. This network is essentially a low-pass filter and, therefore, serves an additional purpose of attenuating the transmitter harmonics.

A concentric terminated line is often used to supply energy to a tuning house at the base of a large array as shown in diagram (c), Fig. 7-16. A concentric line, as the name implies, carries one conductor inside of, and concentric to, a hollow tube. The center conductor is

insulated from the outer conductor by "life-saver" ceramic beads spaced from 3 in. to 2 ft. apart depending upon the size of the line. Such a line has a surge impedance as defined by the formula

$$Z_0 = 138 \log_{10} \frac{D_1}{D_2} \quad \text{ohms} \quad (5)$$

where D_1 = diameter of inside surface of outer conductor.

D_2 = diameter of outside surface of inner conductor.

A coaxial line may be buried underground, laid upon the surface of the ground, or supported overhead as desired.

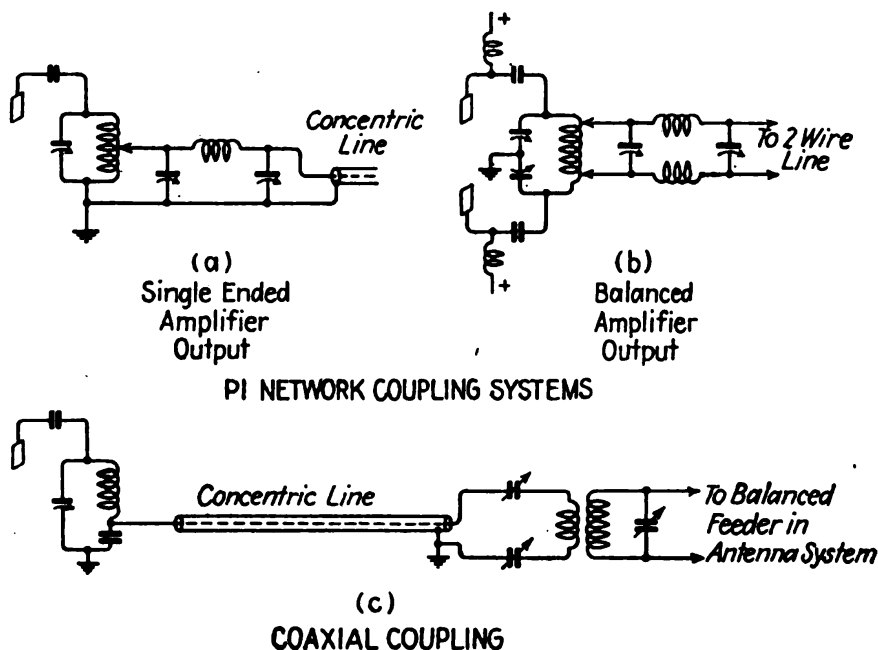


FIG. 7-16.—A pi-network coupling system.

7.8. Construction of Short-wave Antennas.—The different commercial communication companies have different specifications for the details of transmission lines and antenna construction, but the following are good workable values. Transmission-line poles should be at least 11 to 12 ft. above the ground. The cross arm should project from one side of the pole for a distance of about 4 ft., so that the wires of the line will not have the pole between them. The reason is that the pole is generally a poor dielectric, and the line should be kept away from it and the cross arms. Insulators which hang under the cross arm will be less apt to break than any fixed upright type. Insulators about 10 to 12 in. long of a high-grade porcelain or Pyrex glass will generally be satisfactory for transmission-line use at powers up to 20 kw. and over. Insulators with large metal-end caps should be avoided for transmission-line purposes, because the added lumped capacity will change the impedance of the line at this point and will cause reflections.

If the transmission-line poles are about 100 ft. apart, it will be found that No. 6 or 8 medium hand-drawn copper wire will stand the strain and is entirely satisfactory. The spacing for a 600-ohm line will be 12 in. and 9.6 in., respectively, for the above sizes of wires.

If the pole height suggested above is used, the line will be approximately 10 ft. above the ground, which is sufficient. The line impedance must be matched at the antenna. The method of accomplishing this for a doublet has been described, and for other types the matching circuit may be placed vertically on one of the poles at a point where the antenna is to be fed.

A convenient method of matching the impedance of the line, and also of tuning the antennas to resonance, is by means of a small pickup loop of wire with a thermoammeter arranged on a slider, so that it may be pulled along the transmission line, as shown in Fig. 7-17. There is no metallic connection between the line and the loop of wire. The coupling between the loop and the transmission line must be constant.

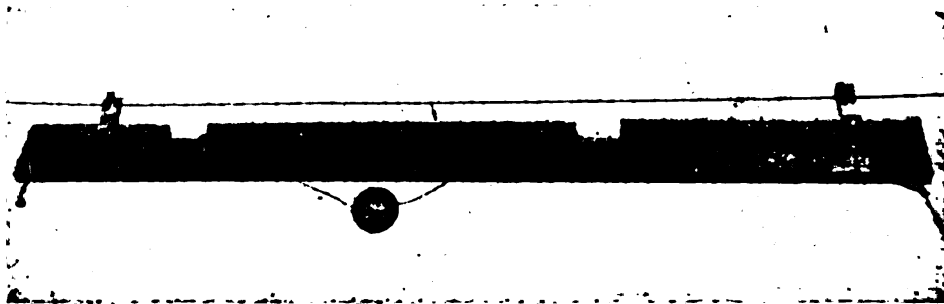


Fig. 7-17.—Scheme for reading current on doublet.

If the antenna is out of tune, it will not be a resistance load for the line, and there will be reflections or standing waves on the line. As the loop slides along the line, there will be peaks of current and low readings one-quarter wave apart. First, the antenna is tuned until the least difference is found between the maximum and the minimum readings. If the antenna is a doublet, its length will have to be decreased one inch at a time, until the best length is found. If the antenna is changed to a directional antenna of the long-wire type, V or diamond, it will generally be possible to make this adjustment on one of the poles by means of a shorting bar.

After this adjustment is made, there will still be reflections on the line, because the degree of coupling will probably not be exactly right to match the line impedance. The next step is to vary the percentage of coupling. If the antenna is a half-wave doublet, the coupling will be across approximately 20 per cent of the length, but this is only a starting point, and the exact distance to tap the feeder lines on each side of the center of the doublet should be determined by trial with the loop and a radio-frequency ammeter to indicate optimum matching and tuning.

The size of meter to use in the pickup loop depends, of course, on the power of the transmitter and the amount of coupling between the line and the pickup loop. *In actual practice it is generally impossible to eliminate entirely all traces of standing waves*, but losses from radiation will not be great if the variation between maximum reading and minimum reading is not more than 5 per cent.

Another method of tuning the doublet is to place a radio-frequency ammeter at the current maximum, which is the center of the doublet, and read it with field glasses, lowering the doublet to change the length. This method would be preferable for the current-standing-wave and voltage-standing-wave feed systems described before, as the loop pickup method, of course, could not be used on these lines. With these standing-wave feed systems it is only necessary to tune the series condensers until maximum current is secured in the line ammeters.

7.9. Ultra-high-frequency Antennas. *a. General Considerations.*—All the antenna systems described under the section Short-wave Antennas



FIG. 7-18.—Yagi-antenna characteristics.

may be applied at ultra-high frequencies when the dimensions are reduced. Systems of half-wave radiators may be made more elaborate since the space required is smaller.

An antenna system employing parasitic radiators can also be made more elaborate. Such a system is generally known as a *Yagi antenna*, one form of which is illustrated in Fig. 7-18.

One method of obtaining a highly directional beam which is not practical at lower frequencies is to mount a large number of radiators in front of a wire screen. The screen acts as a reflector and cuts out the radiation in one direction. A still better method is to place one antenna at the focal point of a parabolic reflector. At very high frequencies above 1,000 megacycles, it is practical to construct a dished-out reflector of sheet metal. At lower frequencies, a parabola can be made of wire mesh and curved in one plane only, as shown in diagram (a), Fig. 7-19. Another type is shown in diagram (b).

b. Guided Waves.—At very high frequencies, another method of transmission and radiation is possible. A hollow metal pipe which is an appreciable fraction of a wave length in diameter is excited by coupling a loop or small radiator to one end of the pipe. The pipe then conducts the energy in straight lines or around corners by virtue of the continual

reflection from the inner walls of the pipe. The end of the pipe can then be made a radiator by giving it one of a number of geometric shapes. Such a *wave guide* and *radiator* is pictured in Fig. 7-20.

c. *The Turnstile Antenna*.—For ultra-high-frequency broadcasting such as frequency modulation or television, an often desired situation is to have as much directivity in the vertical plane as possible for the sake of increased field strength, while having non-directional characteristics

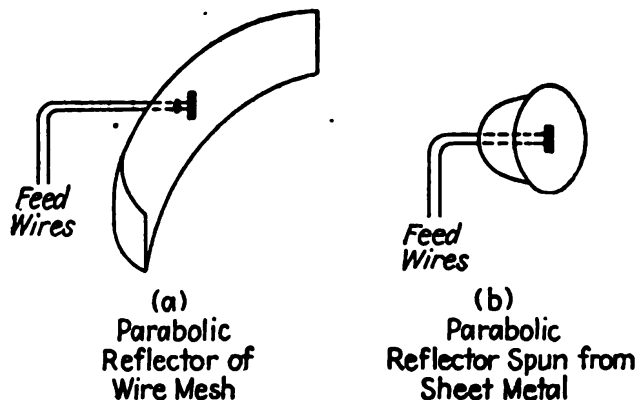


FIG. 7-19.—Ultra-high frequency parabolic reflector antenna.

in the horizontal plane. These conditions are fulfilled by the *turnstile antenna*.

If two half-wave antennas are crossed at right angles and fed with radio-frequency currents in quadrature, a two-phase radio-frequency rotating field occurs just as a rotating field is generated in a two-phase motor. This rotating field is of no particular significance to any one receiver because the receiving antenna is fixed in space and sees only a rising and falling field as from any other kind of transmitting antenna.

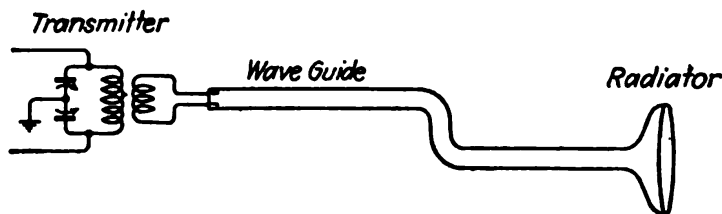


FIG. 7-20.—Guided-wave radiator.

The significant feature is that a uniform field is produced in all directions from the transmitting antenna. Pairs of half-wave crossed dipoles can be stacked one above the other at half-wave intervals and fed in phase to obtain the desired power gain. A *three-bay turnstile* is shown in Fig. 7-21. The 90-degree phase difference between the elements is obtained by feeding one set of radiators through a transmission line which is a quarter wave longer than the line feeding the other set.

d. *Balance Converters*.—Practically all ultra-high-frequency antennas are balanced to ground, and yet it is often desirable to feed them with a

single-ended transmission line, that is, a coaxial or concentric feeder. When this is done, a method is required for going from single-ended to balanced circuits and from balanced to single-ended circuits. Two commonly used systems are illustrated in Fig. 7-22.

The first method consists of surrounding one-quarter wave of the concentric line with a drum so that the outer conductor of the regular transmission line becomes the inner conductor of a quarter-wave coaxial tank, shorted at one end. The outer conductor of the transmission line then exhibits a high impedance to ground at point x , and a balanced load can be attached.

The second method consists of branching a single concentric feeder into two concentric feeders. One of the branches is made 180 degrees longer than the other so the radio-frequency output of one branch is reversed in phase from that of the other. A balanced load can then be attached. In the first case, a 70-ohm balanced load will match a 70-ohm unbalanced line. In the second case, a 280-ohm load is required to match a 70-ohm line because each half of the load to neutral is applied in parallel at the junction of the two branches.

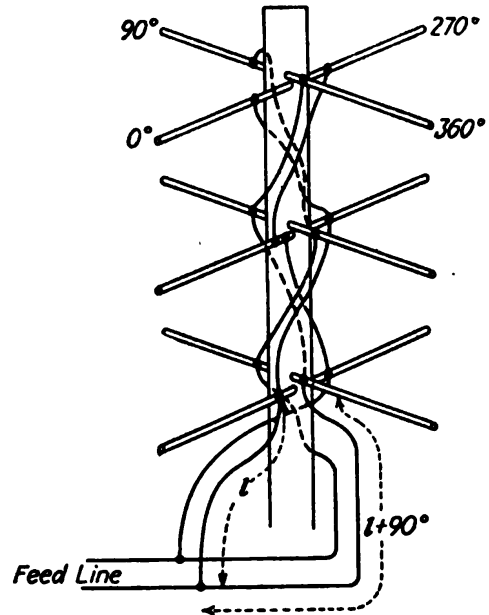


FIG. 7-21.—Three-bay turnstile antenna arrangement.

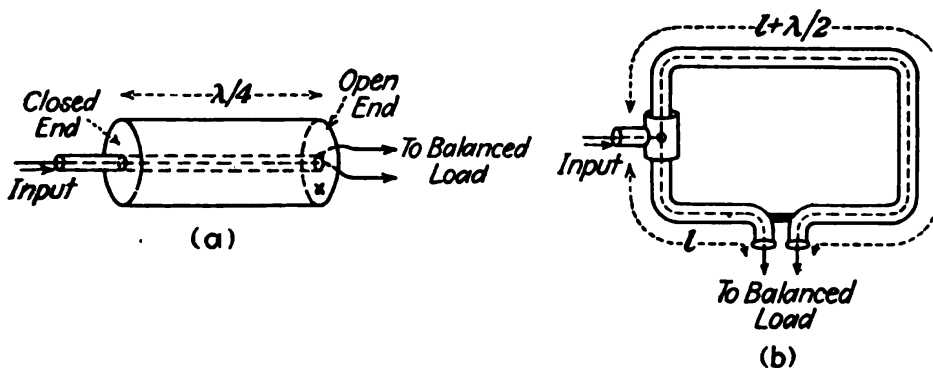


FIG. 7-22.—Ultra-high-frequency concentric line feeders.

For television and for certain special applications, antennas are required to cover a wide band of frequencies. Several principles should be followed to secure maximum band width.

The load (antenna) must match the line with as little transformation as possible. A 70-ohm line connected into the center of a half-wave antenna satisfies this condition.

Let A = spacing in degrees = spacing in wave lengths $\times 360^\circ$

Thus spacing of $\lambda/2 = 180 = A$, and Field = $K \cos (A/2 \sin \phi)$.

If I is the antenna current in each radiator and R is the distance from the transmitter to the receiver in meters, then when $K = 120 (I/R)$ the field strength will be in millivolts at the receiver for free-space transmission. $K = 120 (I/R)$ for $\lambda/2$ antennas, where I is the current in each half-wave radiator.

A plot of this is the field pattern of the antenna of Fig. 7-24 if the points 0,1 are considered as vertical antennas. If they are horizontal antennas, the pattern would be multiplied by the pattern of the individual antennas. For short antennas, to a first approximation, the field is proportional to the cosine of the angle. The field would be

$$\text{Field} = K \cos \left(\frac{A}{2} \sin \phi \right) \cos \phi \quad (6)$$

The above principle can be expanded to a large number of radiators by replacing pairs of radiators by a point source at the center of the pair having a field pattern similar to the pair that it replaces.

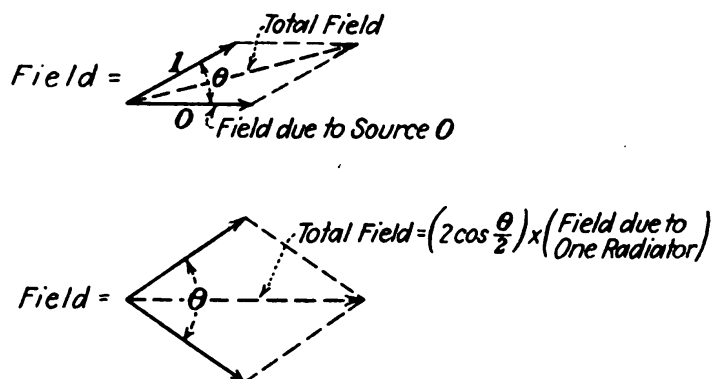


FIG. 7-24.—Resultant field characteristics.

When one antenna is placed near another as in a beam antenna, the current flowing in the first antenna induces a potential in the second and modifies the current flowing in it. Thus, whenever one radiator is tuned by adjusting its length, the second is thrown out of tune. Upon correcting number two, the first is again detuned but to a smaller degree. Mutual coupling exists between the radiators, and it is necessary to calculate this beforehand in order to know the power gain of the array, since otherwise it is impossible to allow for the current flowing in the wires for a given power input.

Suppose a *lazy H* antenna,¹ illustrated in Fig. 7-25, to operate on $29\frac{1}{2}$ megacycles, is specified. Each of the four radiators is one-half wave long and they are fed with equal inphase currents. The input impedance of a

¹ BROWN, G. H., Directional Antennas, *Proc. I.R.E.*, January, 1937, pp. 78-145.

pair of radiators fed as pictured will be around 5,000 ohms. Two pairs are connected in parallel through a half-wave line bringing the impedance to 2,500 ohms terminating a 600-ohm line. If we back up on the line from the antenna a little less than a quarter wave length, the line will be capacitive and can be tuned out by a short-circuited stub whose length will be less than one-quarter wave length. The tuned impedance can be made equal to 600 ohms by adjustment of the position and length of the shorted stub while observing the standing waves of voltage or current from point *B* toward the transmitter. The voltage (as observed by a neon bulb or vacuum-tube voltmeter) or the current (as observed by a thermogalvanometer) will be constant along the line when it is correctly terminated.

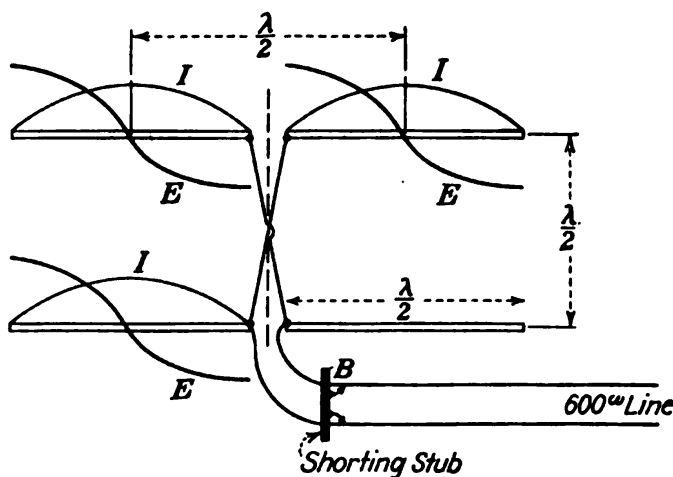


FIG. 7-25.—An H-type beam-antenna characteristic.

The spacing between centers of the radiators will be one-half wave length in each direction, thus,

$$\frac{\lambda}{2} = \frac{300 \times 10^6 \times 39.37}{f \times 2} \text{ in.} = \frac{300 \times 10^6 \times 39.37}{29.5 \times 10^6 \times 2 \times 12} = 16.6 \text{ ft.}$$

where 300×10^6 = velocity of light in meters per second.

39.37 = inches per meter.

f = frequency in megacycles.

The length of the radiators will be about 95 per cent of one-half wave length = $0.95 \times 16.6 = 15.8$ ft.

The pattern in the horizontal plane will be: Field = $K \cos (90^\circ \sin \phi) \cos \phi$. If this expression is plotted as in Fig. 7-26 together with a circle of equal area, the field gain in the horizontal plane can be found. The power gain will be the field gain squared. If the center of the array is placed $\lambda/2$ above ground, the vertical field will be

$$\text{Field} = K_1 \cos (90^\circ \sin \phi) \sin (90^\circ \sin \phi) \quad (7)$$

This may be plotted against the field of a single dipole one-half wave above ground

$$\text{Field} = K_2 \sin(90^\circ \sin \phi) \quad (8)$$

Arranging K_1 and K_2 for equal areas of patterns, the gain in the desired vertical direction equals D/C . K_1 and K_2 are different constants chosen to make the area of the pattern equal.

The overall gain of the system for this particular array will be approximately equal to the horizontal gain times the vertical gain.

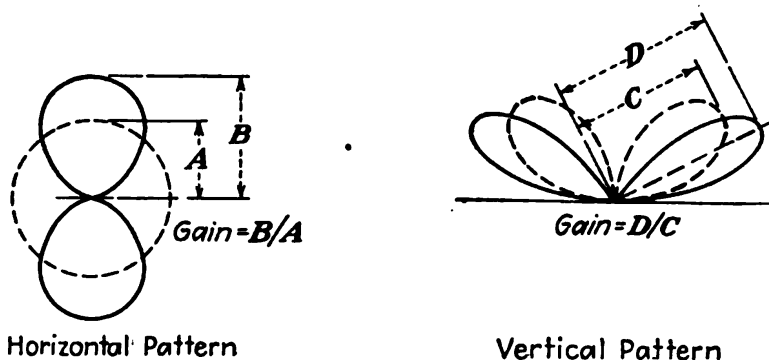


FIG. 7-26.—Field pattern of an H-type radiator.

7.11. Ground Connection and Counterpoise.—In considering the ground connection it must be remembered that the ground forms one plate of a huge condenser of which the antenna forms the other plate when the Marconi quarter-wave radiator is used. On steel ships the ground connection is made to the hull; in a wooden vessel, a large copper plate several square yards in area is fastened to the hull below the water line and a connection made thereto.

At land stations, the ground connection is made by a radial system of wires buried in moist earth so that connection is made over a considerable area. In this way the dielectric loss caused by poor connection to the ground is kept low, and the service range of the station is measurably increased.

For receiving purposes, if connection to a transmitter ground is not possible, a connection to the water-pipe system of the building is in most instances satisfactory. Connection to the steam-heating and gas-pipe systems should be avoided where possible. Many receivers powered directly from the electric-lighting lines do not require a separate ground connection, as sufficient coupling to the ground is secured through the power lines and power-supply apparatus.

Where a good ground connection is not feasible or possible, a counterpoise is used.

Counterpoise.—One of the most important losses due to antenna resistance is caused by dielectric losses in poor ground connections. This is especially true where stations are located on dry, sandy, or rocky land and is due to electron displacement in dielectrics traversed by the electric field set up by the antenna. It uses up useful energy in

a useless action. In other words, if this loss is reduced, more energy is left for radiation purposes.

To reduce this loss, a so-called *counterpoise* is used at some stations, which consists of a network of wires, erected a few feet above the ground but insulated from it and stretched out over the ground in a radial form with the radio-transmitter house as the center.

Theoretically the counterpoise forms one plate of the condenser of which the antenna is the other plate. The entire system of antenna, counterpoise, and ground may also be considered as two condensers in series, the antenna and moist ground far below the surface forming the outside plates, whereas the counterpoise forms the center plate of the two condensers.

Where a counterpoise is erected, the same care should be taken to insulate it as is taken with the antenna. Supports should be as few as possible, and wooden stakes should be kept out of the field formed between the counterpoise and the antenna, as wood has a high dielectric power loss. All connections in the counterpoise should be soldered as in the antenna.

On aircraft and automobiles the metal chassis forms the counterpoise, and for this reason aircraft are carefully bonded to prevent sparking between poor joints in the counterpoise.

7.12. Receiving Antenna.—It may be that receiving antennas do not receive the attention deserved, but this is probably due to the fact that

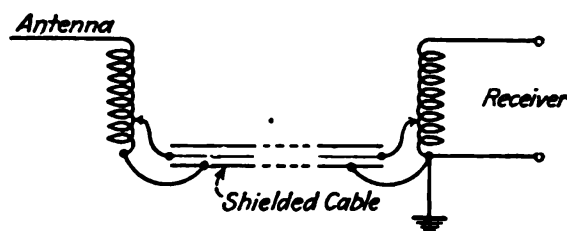


FIG. 7-27.—Receiving antenna coupling system.

receivers have been improved to such an extent that elaborate receiving antennas are generally not necessary except for beam reception. The only obstacle to good reception that can be ordinarily overcome by a special antenna is interference due to pickup from electric appliances, and the best cure for this seems to be to use a low-impedance, shielded-line leadin with a coupling transformer at each end. The cable may be a special lead-covered cable, or a wire covered by Belden braid. The antenna coupler may be connected between one end of the antenna and the transmission line. A standard antenna-coupling transformer is used at the receiver end of the line, the circuit being as shown in Fig. 7-27.

The polarization of the propagated wave is vertical for long waves. From this it would be expected that a maximum signal would be received on a vertical antenna for a given length of wire.

Many different types of antennas have been used for receiving at short waves, ranging from a simple doublet to very elaborate directional designs. There is undoubtedly a very decided *gain* in the ratio of the received signal amplitude to background noise with directional receiving

antennas, besides eliminating interference from signals from other directions. It can be seen that, from the receiving standpoint, gain must be considered in comparison with background noise, as in any receiver additional gain can easily be secured with more amplification, but the background noise is increased at the same time. For this reason a directional antenna has advantages over using additional amplification in the receiver.

In the discussion of polarization at short waves, it was mentioned that a horizontal antenna seems to have some advantage over a vertical arrangement. It is possible to arrange any of the directional-transmitting antennas as receiving antennas. However, if the RCA broadside arrangement is to be so used, there are generally considerable changes necessary in the design. The network is placed horizontally instead of vertically, and the short doublets act as collectors feeding a line. Small condensers are placed in series with each side of each doublet. These are to assist in keeping the wave on the wire in phase with the wave in space. They reduce the loading effect of the short doublets. In this way it is possible to increase the length of the antenna to several wave lengths.

The directivity pattern is with the line and not broadside as with the transmitting design. This receiving antenna is a development from the original Beverage long-wave antenna. The line and collector system is terminated at the end opposite the receiver with a non-inductive resistance equal to the characteristic impedance of the line, which runs from the antenna to the receiver.

Both the V and diamond types seem to have advantages as receiving antennas because of their simplicity. It should be mentioned that the same care should be used to match impedance at the line in a receiving antenna as with a transmitting antenna. Any of the types of transmission line described above may be used; however, it is customary to transpose the line about every 5 ft. to balance out pickup on the line, and special porcelain insulators are made for this purpose. Where interference is particularly bad, the concentric-tube line might prove the best.

In the discussion on propagation at high frequencies, it was pointed out that certain frequencies are reflected best from the Heaviside layer at certain times of the day, but it will be found that, even with these optimum frequencies, there is still considerable fading at times. It has been noticed that fading does not occur at the same time on antennas spaced several wave lengths apart. Advantage is taken of this fact by using two or three separate antennas, each antenna going to a separate receiver. The outputs of the three separate receivers are then combined by special circuits depending on whether telephone or telegraph transmissions are being received.

Coil or loop antennas for receiving purposes have taken various forms, depending on the frequency and the physical space available. At the present time, loop antennas are particularly used in direction finding, both for ships at sea and for airplanes. A loop antenna is generally composed of a wooden vertical frame arranged to rotate on a pivot at the base and to hold the turns of wire in a vertical plane. The directivity is quite sharp and is at right angles to the axis of the coil or loop turns as will be described in the next section.

Note: Antenna requirements for specific receivers are given in connection with the description of the receiver.

7.13. Loop Antenna as Used for Directional Reception.—The operation of the radio direction finders depends on the directional characteristics of the loop antenna. These directional properties may best be understood by studying a simple experiment. Imagine a loop antenna (Fig. 7-28) consisting of several turns of wire wound around a rectangular form, say 5 ft. across, with its terminals connected to a sensitive thermo-

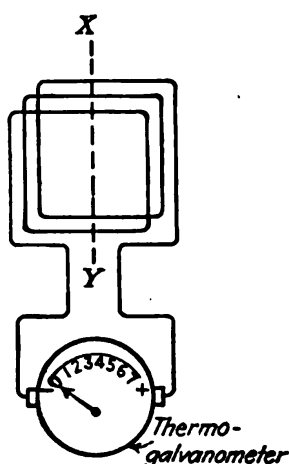


FIG. 7-28.—Simple loop circuit.

galvanometer. Assume further that the loop is mechanically arranged so that it can be rotated on a vertical axis XY represented by the dotted line.

If the loop is now placed in an open space away from any surrounding objects, and a reading taken of the current induced in the loop by a distant transmitter, it will be found that (1) the current is minimum when the plane of the loop is at right angles to the line of direction from which the signals are emanating, and (2) the current is maximum when the plane of the loop is parallel to the line of direction taken by the signals.

The effect on the current flow in the loop caused by orienting the loop to the signal may be graphically expressed as shown in Fig. 7-29. This is called a *figure of eight* or *bilateral characteristic*. The lines radiating from the center show the relative current values. These values are expressed as units by the numbers at the end of each line. When the ends of these lines are connected, a figure-of-eight curve results.

A study of this curve (Fig. 7-29) will show that, when the waves are approaching, or traveling along, a line drawn through points I and III, at right angles to the stationary plane of the loop, the current in the loop is at a minimum value. As the line of travel followed by the waves changes clockwise from the I-III direction, the current in the loop increases. At 45 degrees the current value has reached almost 12 units. At 90 degrees, the point of maximum current flow in the loop,

a value of 16 units is reached. The waves are now traveling along the II-IV line which is parallel to the plane of the loop as shown in the figure. Theoretically this is the position at which a maximum current should be induced in the loop, as will be explained later.

As the line along which the waves travel is oriented farther in a clockwise direction the current commences to decrease until a new minimum is found when the line of wave travel has changed its position, relative to the loop, by 180 degrees. The line of wave travel is now from points III to I, the reverse of I to III. As orientation continues, the current increases to a new maximum at 270 degrees, and then decreases to minimum again when the rotation has been completed.

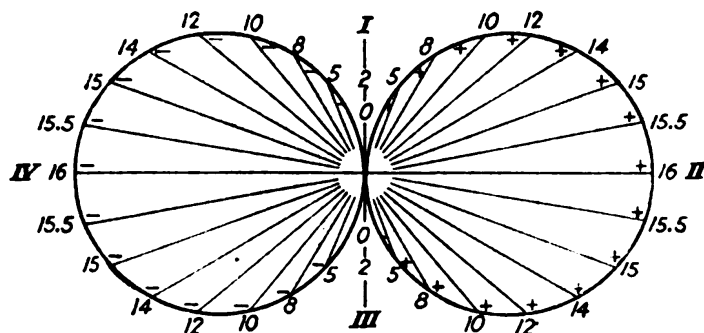


FIG. 7-29.—Bilateral characteristic of loop.

The points of minimum signal are critical, far more so than the points of maximum signal, and these points may therefore be used to determine the *line* of direction taken by the traveling radio waves.

One way of accounting for the directional properties of the loop is as follows: When the wave is approaching along a line perpendicular, or at right angles, to the plane of the coil, the wave front is parallel with the plane of the coil. Therefore, the wave strikes both sides of the loop at the same instant (the horizontal wires contribute nothing to the directional properties of the loop) and induces e.m.fs. of identical phase in both sides of the loop which cancel out, nullifying any tendency for a current to flow. If, on the other hand, the wave is approaching along a line of travel parallel with the loop, the wave front strikes one side of the loop a fraction of a second sooner than it strikes the other side. Although this fraction of time may be only a part of a millionth of a second, the speed-of-current effect is so great that the current in the side of the loop nearest the source starts to flow before the current in the side farthest from the source has time to build up to sufficient proportions to nullify it.

This action may be better understood if we imagine a slow-motion picture of the process. Suppose two vertical wires are set up in a desert spaced 300 meters apart. This distance is chosen because at a speed of 300,000,000 meters per second it will take a 600-meter radio wave 0.000001 sec. to strike the second wire after it has struck the first if the line of travel is parallel with an imaginary line stretched between the two wires.

If the line of travel is across the page and the source is to the left of the diagram, as in Fig. 7-30(a), the e.m.fs. induced in the wires by the 600-meter wave will be 180 degrees out of phase, that is, when the polarity is maximum positive at the top of wire X, it is maximum negative at the bottom of wire Y. If now the tops of the two antennas are connected by a wire, and connecting wires run from the bottoms

of the two antennas X and Y to a sensitive thermogalvanometer, a current will flow in the loop thus formed and will be registered on the meter. The horizontal wires at the top and bottom of the system contribute nothing to the e.m.f. in the circuit. It is found that a maximum current is induced in X and Y when the waves are approaching along a line parallel with a line drawn between the two wires.

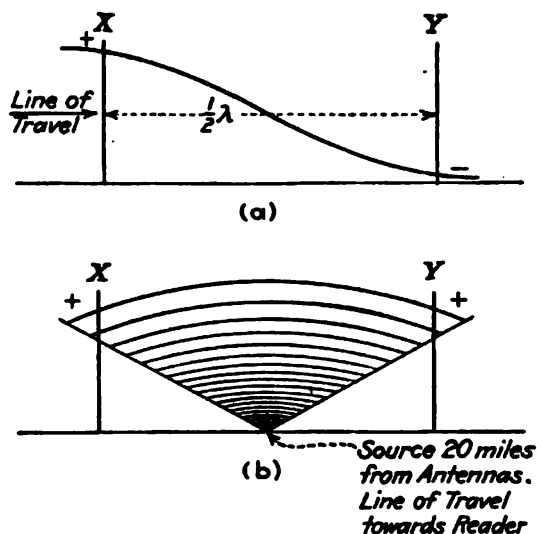


FIG. 7-30.—Effect of approaching wave on two vertical antennas.

of surrounding objects which would distort the oncoming wave. Under practical working conditions these ideal conditions are not usually found, and it is rarely possible to get a sharp minimum signal when the loop is at right angles to the source unless special precautions are taken in the design and installation of the system.

When the point of minimum signal is not critical, there is said to be *residual signal* present. This may be shown graphically as in Fig. 7-31,

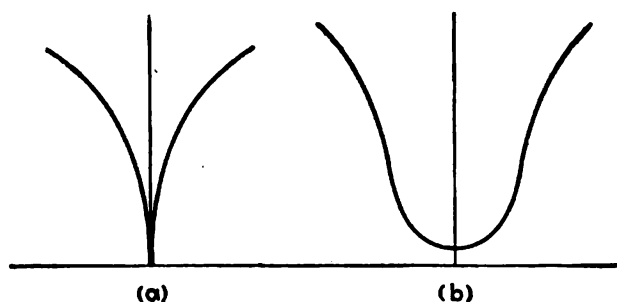


FIG. 7-31.—Signal characteristic: (a) ideal condition of sharp minimum; (b) condition with residual signal present, broad minimum.

where (a) is the ideal condition of sharp minimum, and (b) is the condition with residual signal present. This residual signal may be caused by conditions within the direction-finding equipment itself which cannot be remedied except by changing electrical conditions in the direction-finder circuit and equipment, or it may be caused by conditions extraneous to the direction-finder circuit in which situation no amount of rearranging the direction-finder circuit will effect a remedy.

Let us first consider inherent circuit deficiencies which might cause residual signal. The principle trouble is that caused by *antenna effect* in the loop. Antenna effect is the result of the flow of dielectric currents from various parts of the loop circuit (and from receiving circuits coupled to the loop) to the ground. Some of these paths may not lead directly to the ground but form short cuts to the ground with the same effect. Some of these dielectric currents, as they might flow from an unshielded loop, are shown in Fig. 7-32 as dotted lines. Line *ab* represents the leakage from connecting leads to the ground; line *cd*, the short-cut leakage between the turns in the loop; and line *ef*, the leakage from the loop itself to surrounding objects which are grounded, or directly to the ground itself. There are probably many other paths, but these are the principal ones.

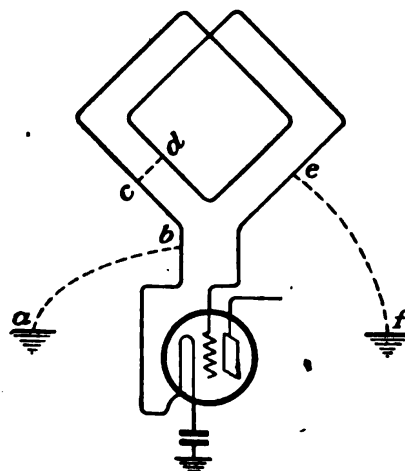


FIG. 7-32.—Dielectric currents (dotted lines) causing antenna effect.

The e.m.fs. produced by the antenna effect are generally 90 degrees out of phase with the e.m.fs. produced by the coil and for this reason can never completely balance out the coil e.m.fs. Also the e.m.fs. produced by antenna effect do not vary with orientation of the coil, or, in other words, no matter how the coil is turned, the antenna effect for a given coil and circuit is the same.

The other principal cause of residual signal or broad minimum is the e.m.fs. induced into the direction-finder circuit by spurious fields produced by near-by metallic objects which form closed-loop circuits. The energy is transferred from these outside circuits by induction, and not by radiation, which, from these circuits, is too feeble to be noticeable. Because the energy is transferred by induction, the potential of the e.m.fs. induced depends upon the orientation of the coil. The effect then varies with coil position and usually results in a point of minimum signal which is different from that which would result if the coil was not affected by these spurious fields.

A source of error in finding the position of minimum signal is introduced by a so-called *night effect*. This effect is noticeable during the period continuing from $\frac{1}{2}$ hr. before sunset to $\frac{1}{2}$ hr. after sunrise and is probably caused by the erratic nature of the wave propagation during the night period. Experience has brought out the fact that this night effect is most pronounced shortly before and after sunrise or sunset.

Errors in the position of minimum signal as caused by night effect are manifest by a rapid swinging of the minimum, which gives the effect that the source is changing its location while the observations are being made. Freak minima sometimes exist

as part of the phenomena, in which the null (point of minimum signal) is noted as merging into several distinct nulls, and again it may become entirely extinct. Considerable residual signal usually accompanies night effect, and bearings taken under these conditions are to be considered as being only approximately correct. At distances less than 100 miles, the error introduced is negligible. It has also been noticed that at times a variable error due to night effect might be reported by a shore direction-finder station while no error is noticed by ships in the immediate vicinity equipped with modern direction finders.

The cause of the so-called *night effect* is an erratic variation in the relative strength of the sky wave at night compared to the ground wave. This results in strong sky waves which are horizontally polarized, that is, their electric field and wave front are parallel, or tend to take this position to the earth's surface. Therefore, when they strike the horizontal wires of the loop, these waves set up a current flow in these wires. These currents tend to nullify the currents flowing in the vertical wires of the loop, which are due to the effect of vertically polarized ground waves and to space waves traveling along the surface of the earth.

As the loop of a radio direction finder is turned on a vertical axis, the relative position of the horizontal loop wires and of the down-coming horizontally polarized sky waves is unaffected by rotation of the loop, and, therefore, the night effect is present regardless of the position of the loop.

As a matter of fact, the horizontal polarization of radio waves takes place during daylight hours as well as at night, but the effect during the daytime is negligible owing to the relative weakness of the sky wave compared with the ground wave on frequencies generally used for direction-finding purposes.

The only remedy for night effect over distances in excess of 100 miles on optimum frequencies is to concentrate the radiation from the transmitter into ground and vertically polarized space waves as is done by the transmission-line antenna used for aeronautical radio-range beacons.

Just as light waves are bent from their normal path of travel when they pass from a medium of one density to a medium of another density, so are radio waves bent when they leave the medium of travel over water and enter an adjoining medium which is over land. For this reason a considerable error might be introduced into any bearing taken by a radio direction finder on a signal that has traveled for an appreciable distance along a coast line owing to the difference in the media of travel over water and land. Any line of direction indicated by a radio direction finder under these conditions should be considered inaccurate. For the same reason, a bearing taken when the radio direction finder is separated from the source by intervening land should be regarded as more or less approximate.

Any distortion of the radio wave before it strikes the loop, be it caused by induction from near-by objects, night effect, or anything else, is referred to as *deviation*. There is nothing that can be done about deviation caused by night effect. Deviation caused by induction from near-by metallic objects can usually be compensated for by the installation engineer. When such compensation has been accomplished, further causes of deviation, such as the moving of huge booms, lifeboats, or other metal objects from their normal position, must be avoided if correct operation of the loop is to be expected.

7.14. Minimizing the Error. a. Reducing Antenna Effect.—The absence of a critical point of minimum signal is mainly due to residual signal which, as has before been pointed out, is that signal which is sometimes present in the arc that should be void of all signal. From a practical standpoint this means that the operator cannot get a minimum

signal, no matter how he turns the loop. This problem presented a great difficulty in the early development of the radio direction finder for marine applications, when large unshielded loops were used.

Upon investigation it was found that residual signal was caused largely by two things, namely, (1) direct pickup due to induction from near-by metallic circuits, and (2) antenna effect due to lack of symmetry on the part of the direction-finder circuit, and dielectric currents.

Both of these undesirable characteristics were minimized by shielding the loop, loop leads, receiver, and all accessories. The continuity of the loop shield was broken at the apex of the loop by insulating fittings.

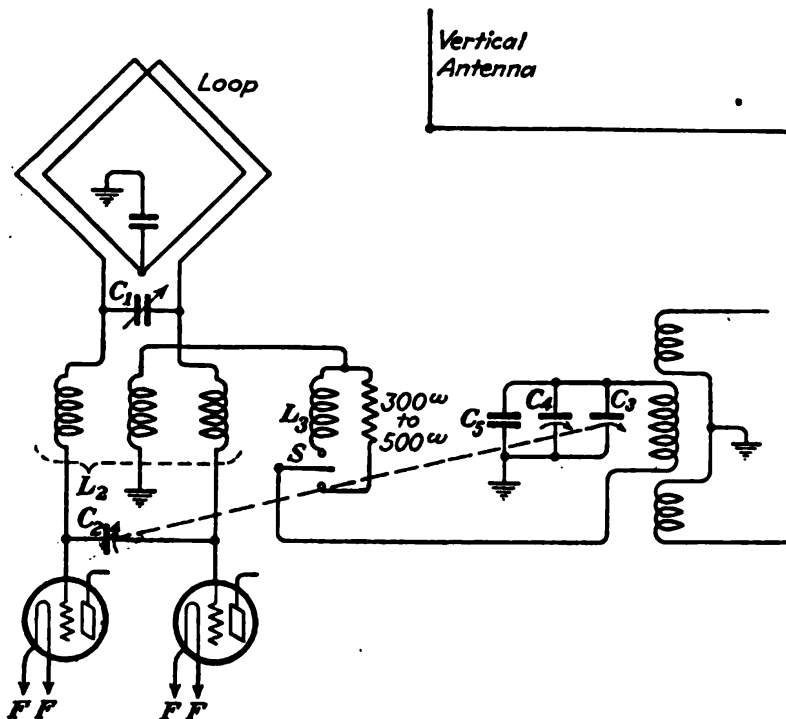


FIG. 7-33.—Fundamental balancing circuit employed to reduce antenna effect.

To improve the electrical symmetry of the loop circuit, push-pull radio-frequency amplification was employed. These were obvious solutions which soon occurred to the designing engineers, but they did not completely solve the problem. Various methods of balancing out the undesired residual signal by the use of balancing circuits were then tried.

The object of the *balancing circuit* is to introduce currents of a definite phase value into the loop circuit, thus balancing out the antenna effect and consequently a large part of the residual signal. The final form of the balancing circuit here used, and shown in Fig. 7-33, is called the *magnetic type* because the action takes place electromagnetically through the coil assembly L_3 . Another type known as the *capacitive balance circuit* achieves the same results through capacitive coupling between the loop and vertical antenna. In the circuit here shown, the condenser C_1

tunes the loop to the frequency of the incoming signal thus making the circuit more responsive (increases pickup) than if the loop were untuned. The antenna tuning condenser C_3 does the same thing for the antenna circuit. Condenser C_4 is a trimmer condenser, and C_5 is a loading condenser. Condensers C_2 and C_3 are ganged to operate together. (See Figs. 16-6 and 16-9, the latter showing the capacitive balance scheme.)

The size of the balancer antenna should be such that it will pick up sufficient e.m.f., which, when used with proper L , C , and R values, will balance out the antenna effect. On some commercial installations, the balancer antenna is a vertical wire about 50 ft. long, raised up about 35 ft. and guyed off to one side to give it rigidity. On other installations, smaller antennas (15 to 25 ft.) have been found sufficient. The exact size is usually not critical and can be found by a little experimentation.

7.15. Effect of Frequency on Deviation.—Various investigators have made different reports on the effect of frequency on deviation. It is generally conceded by authorities in the United States that deviation is affected by frequency. Since its adoption as a practical navigation aid, the marine-type radio direction finder has given very reliable service up to distances approximating 100 miles. At distances up to 50 miles, an average accuracy to within 2 degrees has been noted for bearings taken in the bow and stern quadrants, and an accuracy of 2 to 4 degrees in the beam quadrants when the signals are reasonably strong. This statement applies particularly to the 800-meter radio-compass band but is *probably* true for a wave-length range of 200 to 1,000 meters.

For many years it was believed that the deviation on high-frequency emissions below 100 meters was too great to be compensated for owing to the vertical polarization of these waves which caused the electric component of the wave to lie in the vertical plane of propagation. Thus the majority of the energy reaching the direction-finder loop would be reflected from the Heaviside layer, and any directional effect of the loop would be extremely unstable. This has been found to be not wholly true, and later experiments have demonstrated that, although the deviation is greater at frequencies above 100 meters, the radio direction finder may be reliably used up to frequencies as high as 7,700 kilocycles (39 meters) and even up to 12,000 kilocycles (25 meters) if a good strong ground wave can be received. Directional qualities at the higher frequencies are sufficiently stable to enable fairly accurate readings in the quadrantal sectors with maximum deviation occurring halfway between these points.

7.16. Determining Sense of Direction.—The inherent characteristics of the loop are bilateral in nature, and, therefore, only the *line* of direction taken by an observed signal can be determined by the loop when used alone. It is important, especially on shipboard, to be able to tell from which quadrant a signal is coming. This is accomplished by mixing energy from the balancer antenna (vertical wire) with that taken up by the loop in such phase relation that, when both e.m.fs. are added vectorially,

the e.m.f. passed on to the receiver is greater when the loop points in one direction than when it points in the opposite. This is done by connecting an impedance circuit (consisting of L_s and a 300- to 500-ohm resistance, Fig. 7-33) in series with the antenna by means of a control switch. To understand this it may be imagined that an indicating arrow is fastened to the top of the loop, parallel to the plane of the loop. Then, when the loop and vertical-antenna energies are mixed, the resultant signal is stronger when the arrow points, let us say, toward the source than when it points away in the opposite direction.

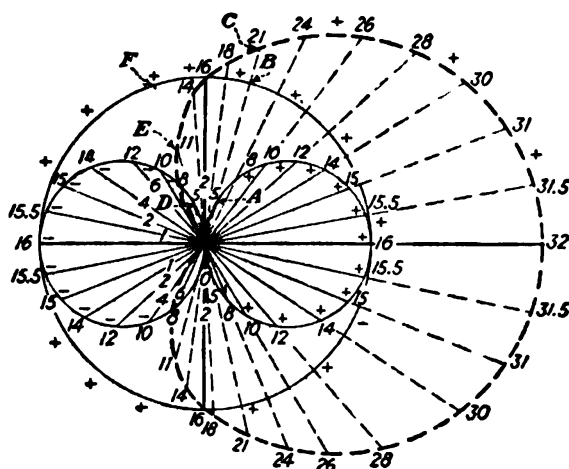


FIG. 7-34.—Unilateral cardioid characteristic.

The e.m.f. conditions present in the loop circuit when the vertical antenna is coupled to it are called the *unidirectional* or *unilateral characteristic* of the loop which is graphically expressed by a cardioid curve as shown in Fig. 7-34.

The minus signs shown around the perimeter of the left-hand circle of the figure-of-eight characteristic of the loop, as shown in Figs. 7-29 and 7-34, indicate that the phase conditions reverse when the source of the signal with relation to the loop is

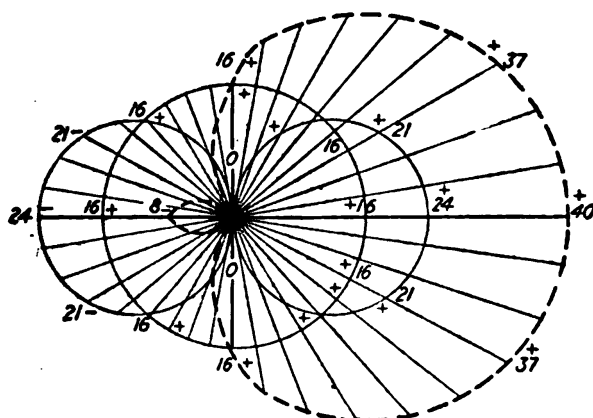


FIG. 7-35.—Non-perfect cardioid characteristic.

reversed. It is to be noted that the positive signs around the cardioid characteristic in Fig. 7-34 are the vectorial result of adding the positive or negative values of the figure-of-eight characteristic to the positive values of the circular characteristic curve which represents the energy from the vertical antenna. This antenna has non-directional characteristics, and, therefore, the phase relationships throughout the entire 360 degrees may be represented as positive. Under proper conditions of operation the relatively positive energy in the antenna is always at least equal to any relatively negative energy which may be generated by the loop, and the cardioid characteristic is

always positive in nature. If the pickup from the vertical antenna is not sufficient, a non-perfect cardioid characteristic will result, as shown in Fig. 7-35.

It is obvious then that the antenna performs two functions in a radio direction-finder circuit, namely, that of a balancer and that of providing a sense of direction. For this reason this antenna is known as a *balancer* antenna, a *sense* antenna, or a *sense-balance* antenna.

The unidirectional characteristics of the loop plus a vertical antenna do not result in a point of maximum signal which is as sharply defined as is the point of minimum signal when using the loop alone. However, in

practical operation it is found that the maximum signal when using both the loop and the antenna (switch in up position to L_1 , Fig. 7-33) is considerably *stronger*, over a fairly wide arc, in one half of the circle of rotation than it is in the other half. This tells the observer that the source of signal lies in the half of the circle in which the signal is stronger. It is then only necessary to shift over to the loop alone (switch S in down position, L_1 out of the circuit, the resistor in the circuit, Fig. 7-33) and utilize its bilateral characteristics to get the line of direction. With this connection the antenna may still feed energy to the balancer circuit, but this energy will not be of the proper phase-angle relationship to distort the current in the loop and give it unidirectional qualities.

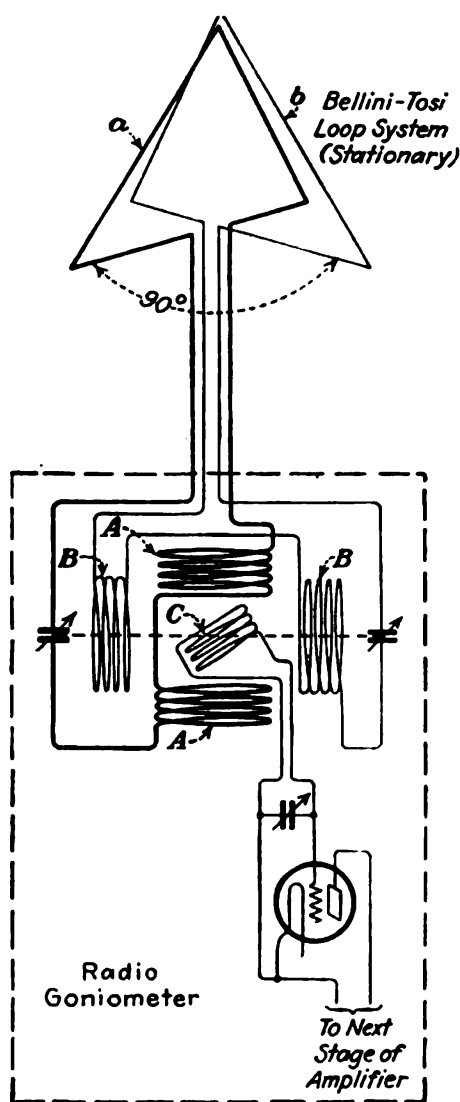


FIG. 7-36.—Radio goniometer utilizing Bellini-Tosi loop system.

tions being taken care of by the radio goniometer, which is the receiver in this system.

The radio goniometer consists of two sets of stationary coils AA and BB (Fig. 7-36) and a movable exploring coil C mounted in a suitable cabinet together with the necessary detector and amplifiers and connected to the loops as shown in the diagram. This box may be placed in the room where the bearings are taken.

7.17. The Bellini-Tosi System.—

This system of radio direction finding was named after its inventors, two Italian investigators. The system utilizes two stationary loop antennas which are erected at right angles and connected to an instrument box which contains a so-called *radio goniometer*. The arrangement is illustrated in Fig. 7-36. The familiar directional properties of a loop antenna are utilized here, but this system differs from the conventional radio direction finder using the rotating small loop in that in this system the antenna is stationary, angular displacement varia-

Let us assume for purposes of explanation that the coil aerial a is parallel to the keel of a ship or fore and aft and that the coil aerial b is athwart-ship or at right angles to a .

In accordance with the well-known directional characteristics of loop aerials, a maximum signal is induced in a loop when the loop lies in a line of direction parallel to the direction of propagation of the oncoming wave. Also, a minimum signal is induced in a loop when the loop lies in a line of direction at right angles to the line of direction of propagation of the oncoming wave.

A study of the diagram will show that a current flowing in loop a must also flow in coil A . Likewise a current flowing in loop b must flow in coil B . Therefore, the current flowing in the coil A and B is in reality the current induced in the loops a and b . If a strong signal is induced in a , a strong signal flows in A . If a strong signal is induced in b , then a strong signal flows in B . Therefore, the field set up in the space around the exploring coil C is similar to the field set up around the loop aerials a and b .

A maximum e.m.f. is induced in the exploring coil when that coil is at right angles to the magnetic field set up around it.

Now suppose a signal comes from the direction in which the ship is headed. A maximum signal is induced in a and flows in A also. If the coil C is oriented so that it is parallel to A , then a maximum e.m.f. will be induced in it and a maximum signal will be passed on to the receiver. If the coil C is now placed at right angles to A or parallel to B , a minimum signal will be passed on to the receiver.

The same action takes place if a signal comes from abeam. In this case a maximum current flows in b and B and a minimum current in a and A , and the receiver responds accordingly as the exploring coil is turned parallel to B for maximum response and at right angles to B for minimum response.

Now suppose a signal approaches from 45 degrees off the port bow. There are now equal e.m.fs. induced in both loops a and b . The fields set up by coils A and B are of such phase relationship that a maximum e.m.f. is induced in coil C when it lies 45 degrees off the parallel position to both coils A and B .

A pointer is attached to coil C which moves over a pelorus scale which shows the bearing of the transmitting station, and its reciprocal, with respect to the ship. If this ship is kept on the course and another bearing taken later, these relative bearings, together with the distance traveled, may be computed to give the exact position of the observing station.

A scheme for coupling a non-directional vertical antenna to a Bellini-Tosi loop system to get a unidirectional characteristic is shown in Fig. 7-37. The theory underlying this action has been explained earlier in this chapter.

The chief disadvantage of the Bellini-Tosi loop system aboard ship is the size of the loops which must be used in order to get sufficient pickup to energize the receiver. When used for transmitting, the large loops used in this system are an advantage over a smaller loop because of the stronger

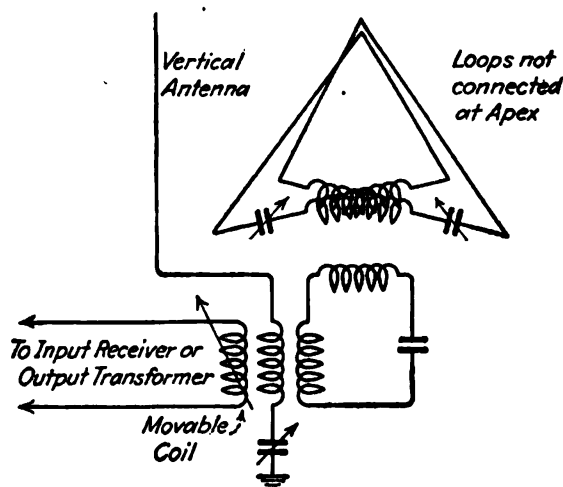


FIG. 7-37.—Scheme for connecting non-directional vertical antenna to the Bellini-Tosi loop system.

field radiated by the larger loops. The Bellini-Tosi system has found some use on European ships for direction-finding purposes. In the United States, its use has been confined to long-distance transocean aeronautical direction finding from shore-base stations.

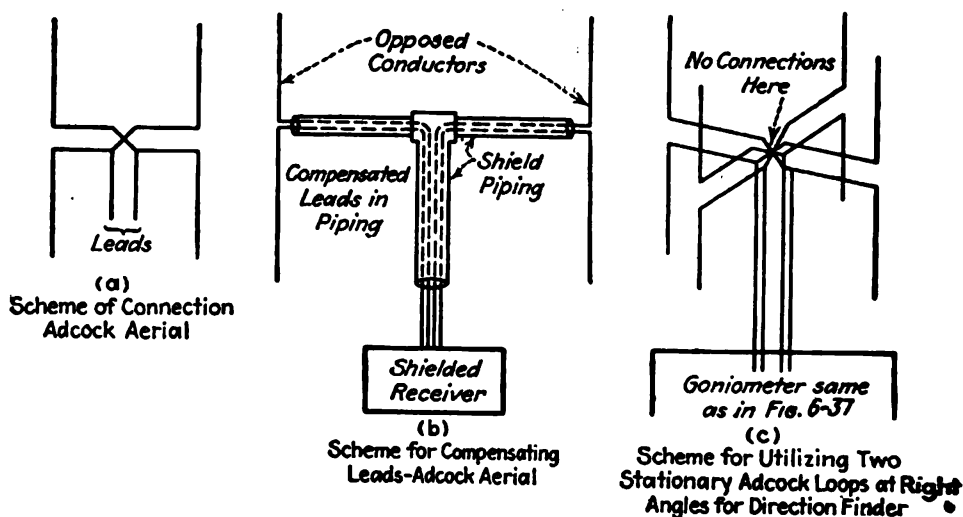


FIG. 7-38.—The Adcock aerial for directional reception.

A modified Bellini-Tosi loop transmitting-antenna system was used on the American airways for radio-range transmitters but they have been replaced by transmission-line antennas which are free from night effects, and which will be described later in Chap. 9.

7.18. The Adcock Aerial for Directional Reception.—This system utilizes a pair of spaced vertical conductors placed end to end as shown in

Fig. 7-38(a) and (b) and mechanically arranged so that they may be rotated. The vertical conductors are the only effective conductors, as the horizontal sections are transposed so that compensation results and any energy picked up by them is neutralized. The same scheme is followed in bringing down the leads from the loops to the goniometer box.

The principal advantage claimed for this system is its freedom from night effects. The principal disadvantage is that loops of large dimensions are required if the pickup is to be sufficient for practical work. If desired, the loops may be stationary, with two loops used at right angles to one another and connected to a goniometer as shown in (c).

The Adcock aerial system gives a symmetrical figure-of-eight characteristic, its theory of operation being similar to that of the closed loop described earlier in this chapter. This system has received considerable attention in Great Britain, but little has been done with it in the United States except that it formed the basis for the development of the transmission-line antenna system used with radio-range beacons.

III. ANTENNA MEASUREMENTS

7.19. Measuring Antenna Resistance.—The power radiated by an antenna can be computed from the formula $W = I^2R$, where I is the antenna current and R the antenna resistance. It is, therefore, sometimes desirable to measure the resistance of an antenna. This may be done by the so-called *resistance-variation method* using the circuit shown in Fig. 7-39.¹

This method requires a vacuum-tube oscillator as a source of undamped waves, an accurate low-resistance thermocouple galvanometer in series with the circuit being measured, and a variable resistance standard. The currents corresponding to given deflections of the thermocouple galvanometer are obtained from a calibration curve, or from the square law $d \propto I^2$ where d is the deflection if the meter follows this law close enough. Under these conditions the equation becomes

$$R = \frac{R_1}{\sqrt{\frac{d}{d_1}} - 1} \quad (9)$$

where R denotes the resistance of the circuit without the added resistance, and R_1 is the added resistance introduced in the circuit.

Referring to the circuit diagrams in Fig. 7-39, several values of resistance R_1 , R_2 , and R_3 are usually inserted in the circuit at R , and the corresponding deflections obtained; the resulting values of R being averaged.

¹ Essentially as given in U.S. Bureau of Standards Circ. 74.

When the thermocouple galvanometer follows the square law accurately, the quarter-deflection method may be used, which eliminates all calculation. When the deflection d_1 is $\frac{1}{4}d$, the equation becomes

$$R = R_s$$

This method requires a variable-resistance standard such that R_s can be varied continuously in order to make d_1 just equal to $\frac{1}{4}d$.¹ Practically the same method is used, if the resistance is varied by small steps, as in a resistance box, interpolating between two settings of R_s . Suppose

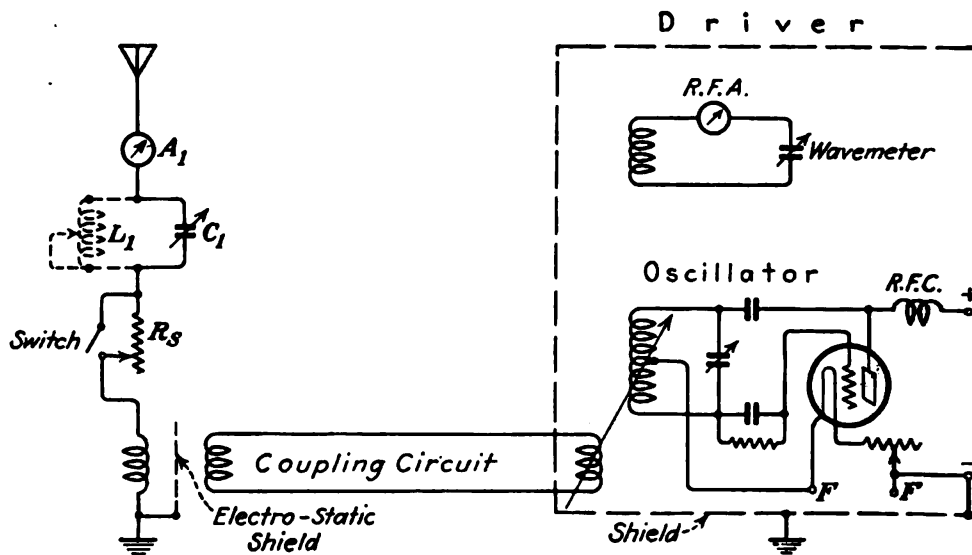


FIG. 7-39.—Conventional method for measuring total antenna-circuit resistance.

that the three values of R_s are R_1 , R_2 , and R_3 , and the corresponding deflection d_2 is slightly less than $\frac{1}{4}d$, and d_3 slightly greater than $\frac{1}{4}d$, then

$$R_s = R_1 + \frac{d_3 - \frac{1}{4}d}{d_3 - d_2} \times (R_2 - R_3) \quad (10)$$

A practical measurement of the radiation resistance by the resistance-variation method may then be readily made, using the equation

$$R_a = \frac{R_s}{\frac{I}{I_1} - 1} \quad (11)$$

where R_a = resistance of the antenna.

R_s = value of the added resistance.

I = current reading without the added resistance.

I_1 = current reading with the added resistance.

¹ $\frac{1}{4}d$ = one-half the current on a current-squared meter. With any other type of ammeter adjust for one-half maximum current reading.

Procedure: 1. Adjust the antenna circuit to resonance with the normal operating conditions of the transmitter. The radiation ammeter (A_1) may be left in the circuit.

2. Take out all R_s resistance by closing the short-circuiting switch.

3. Start driver, and tune it to resonance with antenna circuit.

4. Record current reading on radio-frequency milliammeter (A_1). This becomes the I value in the formula.

5. Do not vary power in driver. Open switch, and insert a small value of R_s .

6. Record current reading on radio-frequency milliammeter A_1 . This becomes the I_1 value in the formula.

The above procedure may be repeated *with four or five different values of R_s* and the results averaged. Accurate results are more likely to be obtained in this way.

The power in the driver must be constant throughout the entire measurement, or the results will be inaccurate.

If a current-squared galvanometer or wattmeter is used in place of the radio-frequency milliammeter, the square roots of the readings must be used for current readings.

The resistance of the radio-frequency milliammeter A_1 , and any additional L or C in the antenna circuit, must be subtracted from the value of R_a , computed as described, in order to get the true R_a of the antenna system as it is under operating conditions.

Some Practical Considerations in Making Antenna Measurements.—The wave-meter should be coupled to the oscillator, not to the antenna-coupling circuit. The variable condenser C_1 must be of low-loss construction and must be calibrated. If the antenna is less than one-quarter wave length or over one-half wave length high, as referred to the operating frequency, a variable inductance L_1 will have to be substituted for variable condenser C_1 . This is shown dotted in the diagram. This condenser or inductance must be entirely away from all grounded shields or screens, and all regular coupling equipment must be grounded or removed. The coupler shown between the oscillator and the antenna may have two or three turns in the antenna side and the same in the link circuit. The diameter of these coils may be about $1\frac{1}{2}$ in., and the electrostatic screen may be made of strips of thin copper running lengthwise on the coil, with all strips soldered to a wire at one end of the coil. However, this wire should not make a closed ring. The decade resistance box R_s must be of a non-inductive variable type, such as is used with bridge circuits. The meter to be used at A_1 may be a 100-ma. thermocouple meter or a Weston thermogalvanometer which reads 115 ma. full scale. The latter meter reads current square.

Great care should be used to get the antenna exactly in resonance before reading. It is generally best to take readings at about 10 points, making a curve several kilocycles each side of the operating frequency. If a reading is desired at the fundamental, the condenser or coil is taken out of its circuit and the oscillator is then tuned to the antenna frequency, and a resistance measurement made using the procedure before described.

The errors due to the capacity of the inductance coil to ground are very serious for a high-impedance antenna, which is approximately one-half wave length high, because of the comparatively high voltages at the antenna terminal.

From the curves of Fig. 7-40, it can be seen what reactance to expect for any vertical antenna if its fundamental is known. Similar curves may be plotted for other types. If it is found that the antenna has an inductive-reactance value, a variable condenser

would be used in the above measuring circuit to tune it. Then, from the capacity value read from the calibrated condenser in the above measurement, a more exact calculation can be made of the inductive reactance of the antenna. For resonance, we know that

$$X_L = X_C \quad \text{or} \quad 2\pi fL = \frac{1}{2\pi fC}$$

The value of f and C are known from the data taken above, so that X_L , the inductive reactance of the antenna in ohms, may be calculated. The antenna-impedance equation is then

$$Z_a = R_a + jX_C, \quad (12)$$

where R_a is the antenna resistance,
 $-jX_C$ is the antenna reactance.

It may here be assumed that the resistance of the low-loss air condenser is zero, but, where the antenna has capacitive reactance and it is necessary to use a loading

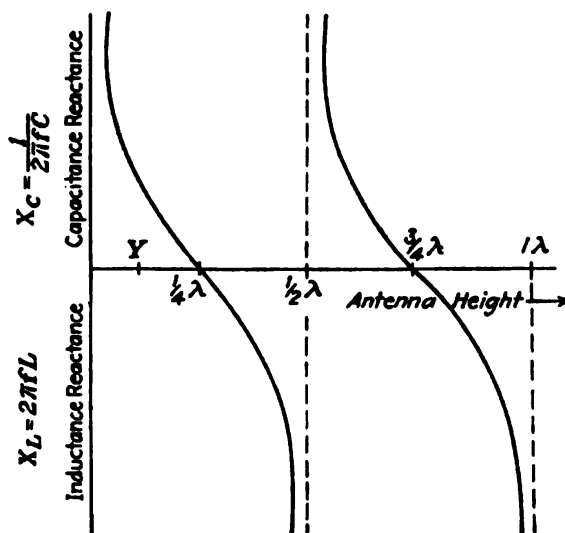


FIG. 7-40.—Reactance curves of a vertical antenna.

inductance, the resistance of the inductance coil cannot be assumed to be zero. The resistance value should be known or measured and may be as high as 10 or 15 ohms. The same equation can be used if, to tune, inductance is added, but the antenna equation will then come out

$$Z_a = R_a - jX_C \quad (13)$$

7.20. Measuring Antenna Impedance.—Since an antenna system is a power-absorbing device in which the power is converted into electromagnetic-radiation energy, it should be apparent that maximum efficiency can be obtained only when the antenna impedance is carefully matched to the exciting impedance in accordance with the fundamental rules of impedance matching.

Designing engineers give this the most serious consideration before designing transmission lines and coupling units to operate in conjunction with the radiating system. By first calculating the reactance of the unloaded antenna, it will also be possible to determine if the antenna is

either highly inductive ($+j$) or highly capacitive ($-j$), which, therefore, makes it a relatively simple problem to determine whether the antenna should be loaded inductively or capacitively. It also provides the necessary information for the design of the transmission line and the coupling units.

An arrangement for determining the reactance looking into an antenna system is shown in Fig. 7-41. The inductance L is a low-loss variable coil, and the capacity C is a variable condenser with a calibrated capacity chart. The capacity in microfarads for each setting may be determined by referring to the capacity chart, and the reactance then computed for the particular setting by the ratio $X_c = 1,000,000/2\pi fC$ ohms.

The procedure for determining the antenna reactance is then as follows: Close the links AC and BD , and open the link AB . This

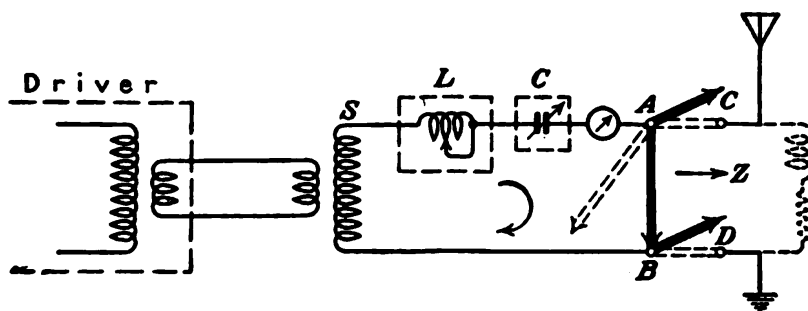


FIG. 7-41.—Circuit for determining antenna impedance.

connects the antenna reactances in series with the circuit components S , L , and C . Now with the drive oscillator adjusted to resonance at the operating frequency, and tuned to the point of maximum dip on its plate circuit direct-current milliammeter (unity power-factor adjustment), the calibrated variable condenser C is adjusted until a maximum deflection is obtained on the radio-frequency ammeter. This reading will then indicate that the entire circuit reactance has been reduced to zero. The condenser setting should then be noted, its capacity determined by referring to the calibration chart, and the capacitive reactance computed from the reactance formula. It is sometimes necessary to readjust the driver circuit after the antenna circuit has been tuned owing to circuit-reflection effects. If, however, the linking circuit between the driver and the coil S is composed of only two or three turns, a readjustment of the driver circuit to unity power-factor conditions will not be necessary. The links AC and BD may now be opened and the link AB closed. The driver is again set into operation, and the circuit LC tuned to series resonance by adjusting the calibrated condenser C . When a maximum deflection is noted on the radio-frequency ammeter, the condenser setting is again carefully noted, and the capacity chart referred to. The reactance at the new setting is

then calculated as before. The difference between the two reactances will then determine the effective antenna reactance. Now, if it was found that the condenser C had to be increased to effect resonance, the antenna system may be looked upon as a $-j$, a capacitively reactive quantity, or vice versa. If standard calibration curves are provided for L and C , it would be a simple matter to determine whether the antenna reactance is a $-j$ or $+j$ value. Thus by taking the previously measured antenna resistance (Sec. 7.19) and the present reactance value $-jX$, the antenna impedance may be readily determined by the expression

$$Z_a = R_a \pm jX \quad \text{ohms} \quad (14)$$

where Z_a is the impedance of the antenna in ohms, R_a the radiation resistance, and $\pm jX$ the inductive or capacitive reactance of the antenna.

7.21. Calculation of Antenna λ and R .—For a quarter-wave flat-top antenna, it is possible to calculate the fundamental wave length λ_f by the following empirical formula:

$$\lambda_f = 4.2 [(\text{vertical height in meters}) + (\text{length of flat top in meters})] \quad (15)$$

The equation is for the L type, but for a T type the flat top on one side of the center is used. The factor 4.2 may increase to values as high as 6 for flat tops of large area.

Radiation resistance of a quarter-wave antenna may be shown to be

$$R = 1,580 \left(\frac{h}{\lambda} \right)^2 \quad \text{ohms} \quad (16)$$

where h = height from ground to center of capacity

h and λ are in the same units, and

λ is considerably greater than the fundamental wave length.

From this the total resistance of the antenna may be estimated. This is simply the radiation resistance (R_a), plus resistance losses in the ground, wire dielectrics, and any other small losses. In general, for one-quarter-wave broadcast antennas this will probably be 5 to 15 ohms; for three-eighths, 35 to 75 ohms; for half-wave, 200 to 600 ohms; for five-eighths, 100 to 150 ohms.

IV. EXTERNAL FACTORS AFFECTING RADIO COMMUNICATION

7.22. Variable Factors Affecting Radio.—There are various difficulties that sometimes stand in the way of perfect radio communication. Some of these difficulties can be minimized, but others cannot be avoided under practical working conditions. These hindrances may be listed as follows: (1) atmospherics, (2) static, (3) fading, (4) day and night effects, (5) seasonal effects, (6) interference from other stations, (7) man-made interference.

1. *Atmospherics* are usually caused by local or distant thunderstorms or by electrical discharges between clouds, resulting in damped waves of an intermittent nature and, depending on their energy level, disturbing to radio reception. These disturbances are also referred to as *strays*, *X's*, or by other names.

Atmospherics produce various kinds of noises in the radio receiver, such as crashes and grinding and clicking noises. A continuous "hiss" is sometimes produced by snow or hail or by magnetic storms. Local lightning produces sharp clicks and crashes.

In the tropics, *atmospherics* are more evident than they are in cooler climates. Radio communication is sometimes rendered impossible in the tropics because of the severity of *atmospherics*. The degree of disturbance caused depends upon the ratio of *atmospherics* to signal energy, X/S . Radiotelegraph signals can seldom be copied when the ratio X/S is greater than 4. Radiotelephone signals usually become unintelligible when the ratio X/S is greater than 2.

The ratio X/S may be decreased by the use of directional receiving antenna or of a loop as used in direction-finder equipment.

2. *Static* is caused by the accumulation of electrical charges on the antenna; that is, the source of the disturbance is the antenna conductor itself. (This is in marked contrast to *atmospherics*, which are caused outside of the antenna proper.) These charges are more easily built up in the antenna conductor if it is insulated from ground by a series condenser. But, regardless of circuit conditions, a charge may build up in the antenna conductor under certain conditions, now to be described. When this charge has reached the discharge value, it discharges through the receiver, causing a clicking or crashing noise.

The amount of static that accumulates on an antenna depends upon weather conditions. Minimum static accumulates when the air is clear and dry. As the air fills with dust, smoke, or moisture, static electricity is deposited on the antenna wires; the denser the air content, the denser and heavier is the static charge deposited on the antenna, and the greater the disturbance to radio reception.

Because more static can gather on a long wire than on a short wire and because a long circuit is required for a high antenna, a short low antenna is desirable where static is bad.

To prevent excessive static charges from building up on the antenna, a high-value *static drain resistor* (150,000 to 200,000 ohms) may be connected from the antenna lead, where it enters the receiver, to the nearest ground connection. A small spark gap, called a *lightning arrester*, may be connected from the receiving antenna terminal outside the radio room to a separate direct conductor to ground for the same purpose and also for the purpose of discharging direct static accumulations caused by local *atmospherics*.

3. *Fading*, which results in a variation in signal strength at the receiver, is caused by the signal arriving at the receiver by two (or more) different routes, the waves coming along one route being out of phase with the waves coming along the other route. Complete fade-out occurs when the two waves are 180 degrees out of phase, thereby canceling each other. To be more explicit, one wave arriving at the receiver may be a sky wave and another, a ground wave, or the total energy may be made up of two sky waves arriving over different routes. Still another condition may consist of a ground wave and two sky waves, all arriving over different paths. But, regardless of the number of waves involved, phase differences may occur, and fading result.

Modulated signals may be subjected to so-called *selective fading*, wherein only one part of a side band fades. The result is serious audio distortion.

A special form of fading known as *flutter fading* usually occurs at night and is caused by changes and disturbances in the ionosphere. At times this ionosphere effect may cause the signal to disappear entirely. This is known as a *radio fade-out*. The various

types of fading caused by changes in the ionosphere may last from a few minutes to several weeks, depending on the operating frequency.

As an illustration of fading, suppose we are receiving a signal of strength 4 on the signal-strength scale; after a few seconds this signal decreases to 1 for a second or so and then disappears; after a few seconds more its strength increases to 3 and then to 4. Such is a typical effect of fading on the audible signal at the receiver. Fading is more pronounced on wave lengths below 1,000 meters than on the long waves.

On radiotelephone receivers, and this would include broadcast receivers, the effects of fading can be minimized by an automatic volume-control circuit (see *AVC* in the Index). However, *AVC* is not effective if the signal disappears, nor is it effective on radiotelegraph receivers, owing to the complete cutoff of the emitted wave when the code characters are formed.

Fading is more pronounced at night than during the day and more so over land than over water.

The only remedy, if any, for fading is a change in operating frequency, as the transmitter power used is not a direct factor in this phenomenon.

4. *Day and night effects* are very pronounced on all radio communication. In general, and not considering the ultra-high frequencies, sky-wave absorption is much greater on wave lengths longer than 50 meters (below 6,000 kilocycles) during the day than during the night. Hence, the range of a station is very dependent upon its operating frequency. For distances greater than 300 to 500 miles, operating frequencies not lower than 4,000 kilocycles are used at night. During the day, frequencies not lower than 7,500 kilocycles are generally used. Greater ranges can be secured over water than over land owing to the lower absorption tendency of water.

When magnetic storms and fading make communication impossible on the higher frequencies, the very low frequencies (wave lengths of 10,000 meters or more) are used by the large communication companies and the government services where the required special equipment is provided.

Inasmuch as the ultra-high frequencies are used only for local communication, day and night effects are negligible. Atmospherics are generally more troublesome at night than during the day, although this condition varies greatly.

5. *Seasonal effects* on all radio communication are pronounced. In general, communication is more difficult when one or both of the stations are located in a hot climate, as the absorption of the wave energy seems to be greater over the terrain in a hot climate than in a cold one. This may be due to the moisture content of the air or to the greater amount of foliage in the hot climate.

Another factor to be contended with in the hot zones is atmospherics, which are nearly always bad in such a climate.

6. *Interference from other stations* is a problem that has been very largely solved by the assignment of different frequencies to different stations, by frequency stabilization through crystal control circuits, and by restricted band widths. In addition, directional reception and the single-signal receiver may be employed (see Index).

Interference between radiotelegraph, radiotelephone (communications), and broadcast stations are each in themselves special problems and must be solved as such. Interference between radiotelegraph stations, for example, is minimized by certain well-established international rules for calling, answering, and handling traffic. Ample frequencies are supplied so that insurmountable interference is rarely a problem with these stations.

Interference between radiotelephone stations is largely solved by the use of exclusive frequencies and rigid rules of traffic handling where interference might occur.

Interference between broadcast stations is minimized in several ways: by each station operating on a frequency that is exclusive within its range of service; by limiting frequency variation of a station to not more than 20 cycles, so that the

maximum beat frequency between interfering carriers on the same frequency is never more than 40 cycles and heterodyning between adjacent carriers is minimized; by a restricted band width for each station; and by limitation of power.

7. *Man-made interference* may be caused by any of the countless devices that operate by electricity, and may take the form of radio-frequency waves, such as are emitted into space by X-ray machines, diathermy devices, neon lights, and electric sparking in any electrical machine, and of low-frequency, directly conducted surges that reach the receiver through the power lines.

If the interference is radio-frequency in character and is radiated into space, the remedy is to prevent the radiation at the source by adequate shielding of the offending device or by enclosing it in a shielded enclosure or room. The shielding is in all cases grounded.

If the interference is a low-frequency, directly conducted surge through the power lines, the most effective remedy is to connect a filter between the offending device and the power lines. A less effective method is to connect the filter between the receiver and the power line.

An effective filter consists of an iron-core choke coil in each side of the line and two 1-mf. condensers in series, with the center connection grounded, connected across the line. If this filter does not work when first tried, reverse it to get the choke coils on the side of the grounded by-pass condensers where they may offer additional impedance to any interference energy that is not grounded through the by-pass condensers before it reaches the choke coils.

Some devices may cause interference by radio-frequency radiation as well as by low-frequency surges through the power lines. To minimize interference of this type, it is necessary to employ both shielding and filter devices.

CHAPTER 8

FREQUENCY MODULATION

The basic principle of frequency modulation has long been known but not practiced until recently. Just prior to 1914, frequency modulation was seriously considered as a suitable means for transmitting intelligence. At that time, mistuned circuits were employed to convert the frequency-modulated wave to an amplitude-modulated wave and this was detected by conventional means. In 1914, a few short years after the discovery of the *audion*, or three-element vacuum tube, by Lee de Forest, the amplifier and modulator tubes were technically advanced to such a stage that many of the problems of amplitude modulation were solved, and as a result frequency modulation was practically forgotten for approximately 8 years. In 1922, J. R. Carson,¹ in a mathematical treatise, indicated that contrary to belief an even wider percentage of band width was required than the conventional AM (amplitude-modulation) system. This was confirmed later mathematically in other papers.

For 30 years, the major problem of communication by radio was man-made interference and static, which are difficult to discriminate against because these types of noise are composed of nearly all frequencies in the spectrum. Shortly after 1925, E. H. Armstrong conceived that a frequency-modulation circuit might be a better system from the standpoint of noise discrimination. Keeping in mind Carson's conclusions of a few years before, Armstrong at first experimented with an FM (frequency-modulation) system with very small frequency deviations in order to maintain as narrow a transmitting band width as possible. There was no noticeable noise improvement. At a later date, Armstrong observed that if wide frequency deviations were employed, greater discrimination against noise was possible. It was also concluded that the wider the band width, the greater the useful signal strength, so that the overall signal-to-noise ratio was considerably increased. Carson's theoretical treatment showed that an infinite band width is required for FM. Armstrong showed that *that portion of the band width which is of significance is no higher a percentage (in fact less) than at broadcast frequencies*. These observations led toward a new movement in the development of FM for general use.

In 1934, after a number of years of experimental work at the Marcellus Hartley Research Laboratory at Columbia University in New York,

¹ CARSON, J. R., Notes on the Theory of Modulation, *Proc. I.R.E.*, Vol. 10, p. 57, February, 1922.

Armstrong moved his experimental transmitter atop the Empire State Building and increased the power to 2 kw. at 44 megacycles. These tests were discontinued in the latter part of 1934. Finally in early 1937, Armstrong began the construction of a high-powered FM transmitter at Alpine, N.J., to demonstrate the feasibility of this method of radio transmission. The results of these tests are now well known to the radio world and have resulted in an acceleration of the development in this field.

I. THE TRANSMISSION OF FM WAVES

8.1. FM Compared with AM.—The process of superimposing intelligence on a radio-frequency wave is termed *modulation*. A continuous radio-frequency wave possesses three defining characteristics—amplitude, frequency, and phase. In AM, the amplitude of the radio-frequency wave is varied in accordance with the intelligence, whereas the frequency remains constant. On the other hand, in FM, the frequency varies and the amplitude remains constant. The phase-modulated wave is essentially the same as an FM one, the chief exception being that in phase modulation the phase deviation is directly proportional to the audio frequency, whereas in FM the phase deviation is inversely proportional to the audio frequency. Also the initial modulation in a phase-modulated system is small and is measured in radians or degrees or in what is the same thing, fractions of a cycle. This latter method of modulation is not generally used—one of the principal objections being the very wide frequency channel required.

From an overall point of view, there are a number of important advantages of FM over AM. In the receiver, higher fidelity and a very much lower noise output is obtained. The general nature of FM circuits is such as to admit of amplification of all audio frequencies without discrimination. This is due to the fact that the channel width in FM is wide enough to allow the passage of all audio frequencies up to 16,000 cycles per second. This is not true in AM systems since at broadcast frequencies the channel allowed on either side of the carrier is 5 kilocycles, and thus an audio frequency higher than 8,000 cycles per second cannot be transmitted without serious interference between stations.

An improved signal-to-noise ratio is also obtained, since static and man-made interference are chiefly an amplitude variation and not a frequency variation. FM systems therefore have an inherent advantage in discriminating against noise and interchannel interference.

From the standpoint of the transmitter, greatly reduced interference between stations results due to the fact that an FM wave has the desirable characteristic of excluding all except the strongest signal. In addition to less sky-wave interference in the allotted frequency band for FM, FM circuits allow radio-frequency transmitting tubes to be operated at their

maximum ratings and hence at their maximum efficiencies since no amplitude variations are present.

The outstanding change in the transmitter is the system of modulation. However, this is not the only important change. Among other changes, two additional ones are the method of frequency control and the method of operation of the tubes. FM transmitters operating in the 50-megacycle region are also physically smaller for a given power output than the AM transmitters.

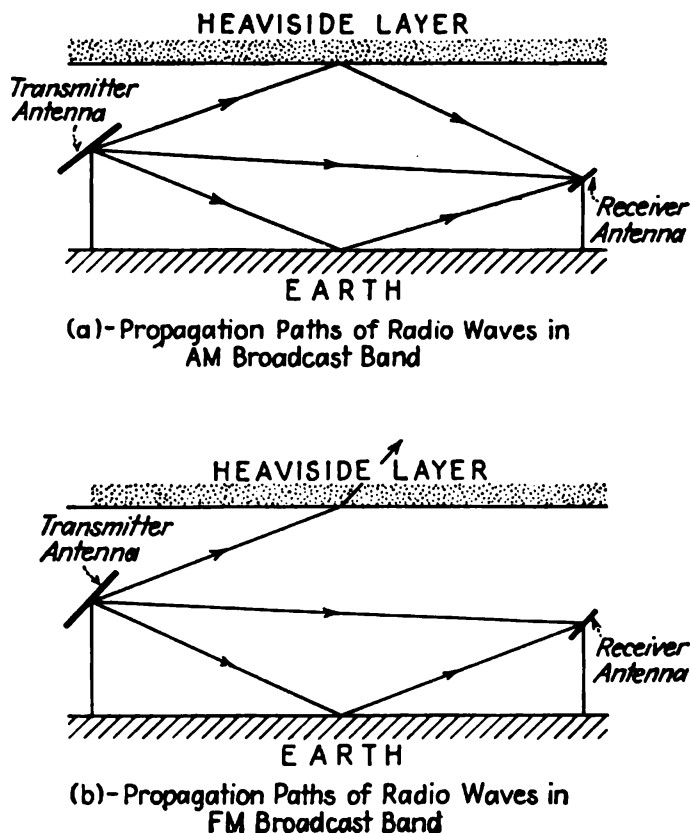


FIG. 8-1.—Propagation paths of 1-megacycle and 50-megacycle radio waves.

In the FM receiver, there are two chief differences from the conventional superheterodyne receiver. (1) The detector stage has been replaced by its FM counterpart, the *discriminator*. (2) Another additional circuit called the *limiter* is included. The limiter insures that the signal wave is free of variation in amplitude and thus full advantage is taken of the ability of an FM wave to discriminate against noise in the form of amplitude variations. The subject of receivers will be discussed in a later section.

FM antenna construction requires that greater care be exercised in guarding against radio-frequency losses in supporting structures and near-by objects. The chief difference, however, is the physical size of FM antennas compared with AM antennas, keeping in mind the respective frequencies at which these antennas are operated. Half-wave antenna

dimensions are approximately 500 ft. for AM and only 10 ft. for FM. A high antenna is important in FM, and this is realized when it is understood that doubling the antenna height will increase the power at the receiver input terminal by 6 db for the same transmitter antenna power. Both high-angle and low-angle radiation is reflected from the Heaviside layer for AM but not, as a rule, for FM. This greatly reduces the disturbance due to the effect of "skip" distance. This is shown in Fig. 8-1. This shows that there are three signal paths for AM and only two for FM. Theory indicates that an FM wave is not expected to be received satisfactorily beyond the horizon. Fortunately, however, practice shows that the actual coverage area is roughly nine times greater than the calculated area. This practical fact is very desirable and much more than the most optimistic expectations. The advent of FM has relieved an already congested frequency spectrum and allows more efficient use of the wave lengths. FM, however, has not demonstrated the ability to cover long distances mainly because of the operation at high frequency. Accordingly, AM transmitting stations on clear channels will continue to serve effectively for rural coverage. FM stations, which are a comparatively small distance apart, will not produce interference to the extent that AM stations will. Therefore, frequency-allocation problems will be rendered much easier.

8.2. Interchannel Interference.—One of the chief advantages of FM over AM is the ability of an FM system to exclude all except the strongest

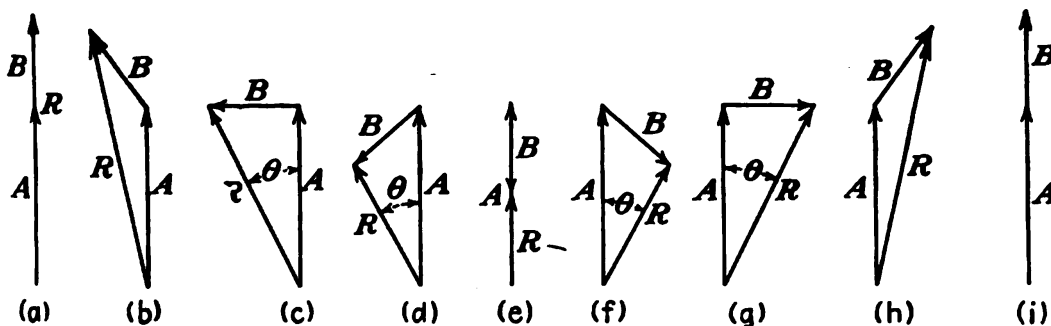


FIG. 8-2.—Vectors showing the resultant of two angular-modulated waves.

signal. This results from the fact that when two FM waves of the same carrier frequency are added, the total amount of angular modulation is not the sum of the individual modulations as in AM. For example, assume two FM carriers of amplitudes A and B , where A is twice as large as B , as seen in Fig. 8-2. First, let A be unmodulated. Line R is the resultant vector and is the sum of the two carriers. No matter what the variation of vector B is, the total angular variation between the desired signal A and the resultant R (which is received and heard in the loud-speaker) cannot exceed an angle that is slightly greater than the angle whose tangent is B/A . In this case, B/A is $\frac{1}{2}$ and θ is slightly less than

30 degrees. This corresponds to less than half a radian.¹ It is evident that the maximum angular variation the resultant signal R deviates from the desired signal A (caused by the undesired signal B) is no more than $\frac{1}{2}$ radian. However, the possible modulation of A is many angular radians, and a variation of $\frac{1}{2}$ radian caused by the vector B is insignificant. Therefore, the interference of B is negligible although B 's magnitude compared with A is not negligible, as shown when B is rotated through 360 degrees in diagrams (a) to (i), inclusive. This shows that the desired signal need be only 50 per cent greater than the undesired signal in order that there shall be no interference in FM. In AM, however, an undesirable signal of only 1 per cent of the desirable signal will cause objectionable interference. This fact suggests that many FM stations can be assigned to the same carrier frequency and operate at fairly close distances from each other.

8.3. Theory of FM.—It is easy to imagine what happens when the condenser of an oscillator is swung back and forth very rapidly. Since the frequency of oscillation is dependent on the capacity in the tuned circuit, it is evident that the oscillator frequency is changing almost instantaneously from one value to another.

Let such a condenser have its dial calibrated with a zero marker in the center and divisional markers to the right and to the left of the zero point (Fig. 8-3). If the condenser is adjusted at the zero point, the oscillator will generate a frequency called its *center*, or *rest*, frequency. For purposes of better illustration, assume that the center frequency is 50 megacycles and that it is desired to transmit a 400-cycle audio note. Further, assume that it is physically possible to tune the condenser from the zero marker to the right or plus 50 divisions, then back again through zero to minus 50 divisions, and forward again to zero at the rate of 400 of these operations per second. The output from the oscillator is then an FM wave modulated with an audio tone of 400 cycles per second. Note that the tone or modulating-signal frequency is dependent on the number of times the oscillator frequency passes through its rest point, or center frequency. Now instead of swinging the condenser plus or minus 50 divisions, let it be swung between the wider limits of plus or minus 100 divisions. If a receiver should be tuned to this latter FM wave, the same 400-cycle tone would be heard in the loud-speaker except that now this tone is much louder. The change from a maximum swing of plus or minus 50 divisions to a maximum swing of plus or minus 100 divisions means a change in the volume or a change in the percentage of modulation of the modulating signal. Whereas in the first case the frequency of the oscillator may be swinging from 50 megacycles minus 50 kilocycles to 50 megacycles plus 50 kilocycles, in the second place it varies from 50 megacycles minus 100 kilocycles to 50 megacycles plus 100 kilocycles.

¹ A radian is the angle at the center of a circle subtending an arc whose length is equal to the radius as shown in a vector.

This increased deviation of the oscillator frequency from its rest frequency denotes an increase of amplitude of the audio signal. FM broadcast transmitters are required to deviate from the center frequency by 75 kilocycles for 100 per cent modulation.¹ It must be remembered that the rate of change of frequency about the center frequency must vary as a sine curve if the modulating signal is a sine curve. To revert back to the mechanical analogy, a sine variation of the capacity can be obtained by

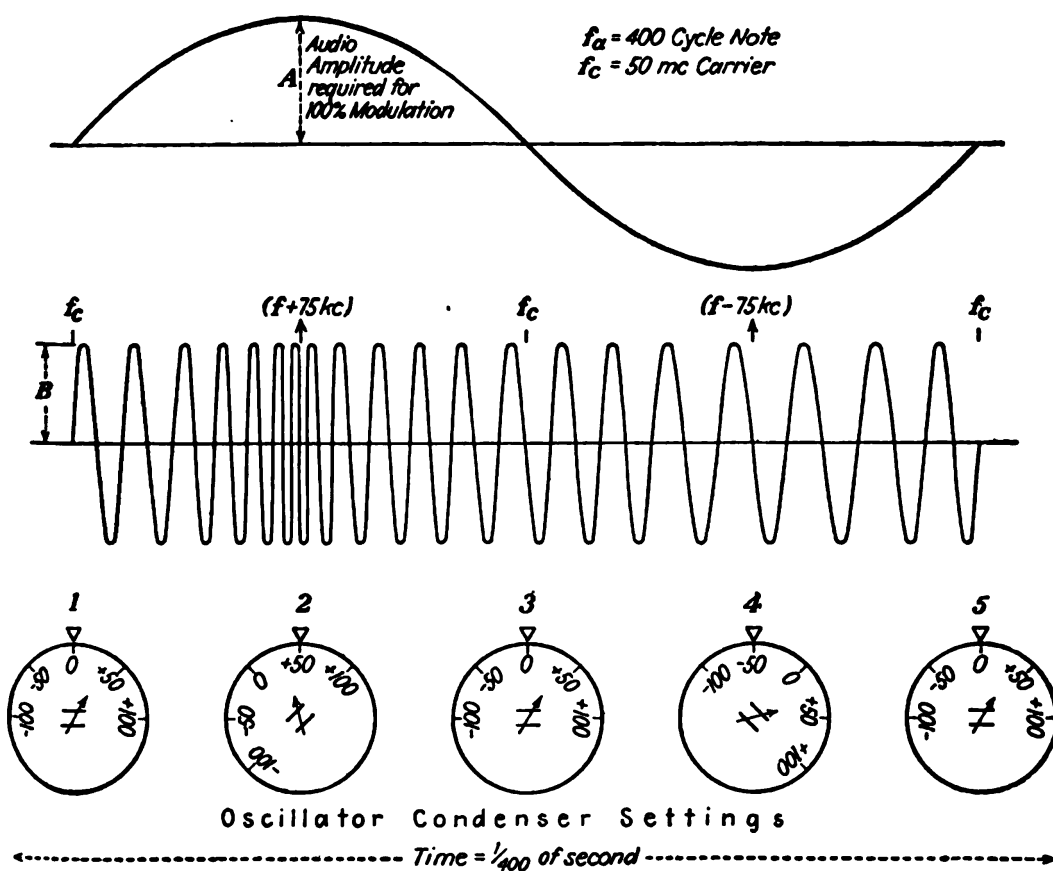


FIG. 8-3.—Frequency-modulated wave.

mechanically coupling the condenser dial to a clock pendulum. It is a well-known principle that a swinging pendulum follows a sinusoidal law.

No such mechanical system as described above can be adapted to frequency modulate a transmitter with the wide variations of amplitude and frequency of speech and music. This type of modulation must be accomplished by electronic means for all FM transmitting sets.

Referring again to Fig. 8-3, an expression for the audio signal is

$$e_a = A \sin 2\pi f_a t \quad (1)$$

where e_a = the instantaneous audio voltage; A = the maximum audio amplitude. f_a = the audio frequency in cycles per second; t = the time in seconds.

¹ Hence, modulation percentage in FM is defined as the percentage of the maximum (75 kilocycles) swing that the frequency swings through at any given time.

If the high-frequency carrier is not frequency modulated, the expression for the instantaneous carrier voltage is

$$e_c = B \sin 2\pi f_c t \quad (2)$$

where e_c = the instantaneous carrier voltage.

B = the maximum carrier amplitude.

f_c = the carrier frequency in cycles per second.

t = the time in seconds.

Now let the high-frequency carrier as expressed by Eq. (2) be frequency modulated by an audio frequency as expressed by Eq. (1). The result is an expression for an FM wave which indicates the character of this wave

$$e = C \{ J_0(m_p)[\sin (2\pi f_c)t] \\ + J_1(m_p)[\sin 2\pi(f_c + f_a)t - \sin 2\pi(f_c - f_a)t] \\ + J_2(m_p)[\sin 2\pi(f_c + 2f_a)t + \sin 2\pi(f_c - 2f_a)t] \\ + J_3(m_p)[\sin 2\pi(f_c + 3f_a)t + \sin 2\pi(f_c - 3f_a)t] \\ + \dots \} \quad (3)$$

where e = the instantaneous value of the FM wave.

J_n = the amplitude of the n th side band.

C = the constant amplitude of the FM wave.

m_p = the deviation ratio.

Although this latter equation may look long and complicated, it does tell much about an FM wave. Hence, it is well worth while to study its meaning for a clearer understanding of FM.

The many terms merely indicate that, unlike amplitude modulation, there are many side bands or side frequencies. The constant C , a factor which applies to all of Eq. (3), indicates that the amplitude of an FM wave is constant and does not vary as an AM wave. This important fact allows the tubes of an FM transmitter to be operated at all times at their maximum ratings and high efficiencies. No allowance is necessary to be made for modulation peaks as in AM systems. This provides for economical construction, operation, and greater portability with a given power output.

The term m_p is called the *phase deviation* and is similar to the term defined as the modulation index in AM. It is described by the following equation:

$$m_p = \frac{\text{maximum frequency swing}}{\text{frequency of signal voltage}} \quad (4)$$

where m_p is in radians.

For a practical illustration of Eq. (4), assume a maximum frequency swing that corresponds to 100 per cent modulation, or 75 kilocycles. Also, let a signal frequency of 15,000 cycles per second be transmitted.

Substitution of these values in Eq. (4) shows that the deviation ratio m_p is 5. It is evident that if speech or music is used to modulate the carrier, the signal frequency may vary anywhere in the audio range from about 50 to 15,000 cycles, and therefore m_p also varies from 5 to 1,500. [To obtain 1,500, substitute 75 kilocycles and 50 cycles per second in Eq. (4).]

For the moment, let us examine the J terms that appear in Eq. (3). These J terms are called *Bessel's functions* of the first order and each one, that is J_0 , J_1 , J_2 , etc., is different from the others but all are of the same

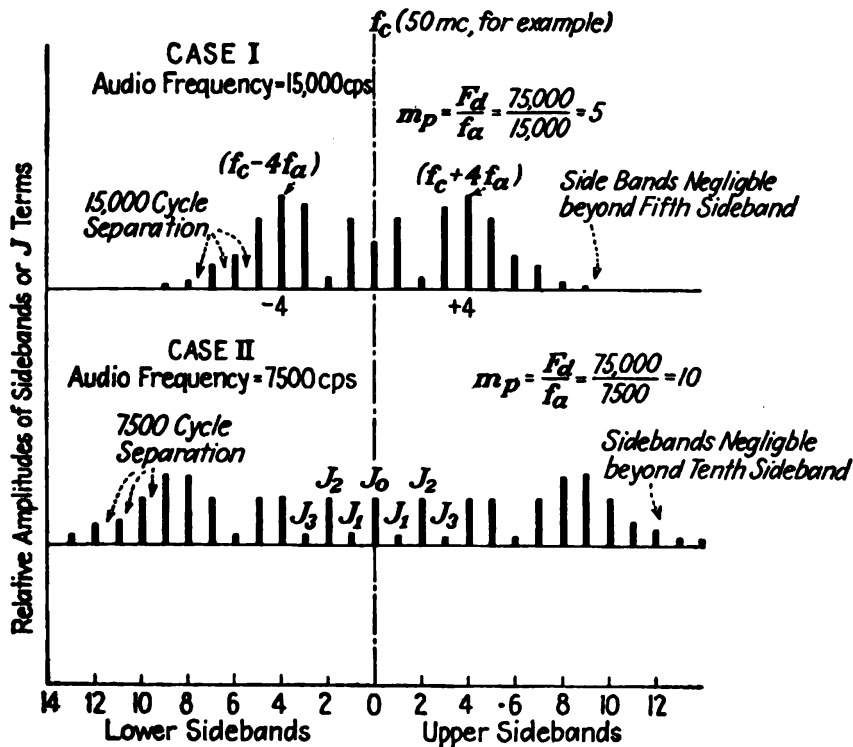


FIG. 8-4.—Spectrum analysis of a frequency-modulated wave.

general nature. These J terms are expressed in terms of m_p , and if m_p is a fixed value (5, for example) each of the J terms has a definite fixed value. However, if m_p varies, as it does when speech or music is the modulating signal rather than a single-frequency note, then each of the J 's vary also as can be expected.

The value of each of these J 's shows that the amplitudes of the side bands with which they are associated are also varying with modulation. For example, referring to Eq. (3) it is seen that J_0 represents the amplitude of the carrier frequency or rest frequency. This is realized when it is observed that J_0 is factored into the term $\sin 2\pi f_c t$ in which only the carrier frequency f_c appears. Likewise J_1 represents the amplitudes of the first upper and lower side bands symmetrically displaced about the carrier frequency f_c , and so on, for the remaining side bands shown in Eq. (3).

The fact that an FM wave is composed of an infinite number of side bands indicates that an infinite band width is required. Fortunately, however, a vast majority of the sidebands is of no significance and those that remain carry most of the intelligence energy. This allows even a smaller percentage band width to be used than is used for AM broadcast bands.

An unusual and interesting fact is revealed in Fig. 8-4 which shows that the order of the side bands which are important is approximately equal to the deviation ratio m_p . For example, case I of Fig. 8-4 shows that above the fifth side band the remaining side bands fade forever into insignificance, and in this case the value of m_p is 5. In case II the value of m_p is 10, and an inspection of this spectrum shows that the side bands above the tenth side band are of no importance. This remarkable behavior makes this practical fact easy to remember.

Another important point is that, regardless of the frequency of the modulating voltage, the band width remains approximately constant over the audio range for a given percentage of modulation. This is seen from an inspection of Eq. (4) which tells that the deviation factor m_p is inversely proportional to the frequency of the modulating signal. For example, if the modulating signal were 50 cycles, the value of m_p would be 1,500, indicating the 1,500 upper and lower side bands are significant and should not be neglected. However, since these side bands are spaced only 50 cycles apart they occupy only $2 \times 1,500 \times 50$, or 150, kilocycles of band width. If a modulating signal of 15,000 cycles per second were used, approximately five upper and five lower side bands are of significance. In this case, the side bands are 15,000 cycles apart. Here the band width is $2 \times 5 \times 15,000$, or 150 kilocycles, which is the same as before. Therefore, the minimum required band width is approximately 150 kilocycles in the 50-megacycle region of the spectrum. However, the FCC allows a channel of 200 kilocycles to permit high-fidelity and low-noise transmission for FM broadcast stations.

The total energy in an FM wave is constant because of the constant amplitude. The relative amount of energy in each of the side bands varies with the degree of modulation and also with the frequency of the modulating signal. With zero modulation, all the energy is confined to the carrier frequency, or rest frequency. At other degrees of modulation, the energy at the carrier may vary down to zero, and therefore this carrier energy is distributed among the other side bands.

8.4. Systems of FM.—One of the simplest methods of generating an FM wave is by means of the circuit shown in Fig. 8-5. This is a conventional oscillator circuit which employs a condenser microphone as its tank capacity. When speech or music is impressed on the condenser microphone, the attendant variation in the tank capacitance accounts for a similar variation in the oscillator frequency. This frequency variation

is in direct accordance with the variation of the speech or music impressed on the condenser-microphone diaphragm. The output of the oscillator is a wave which is frequency modulated.

Unfortunately, this method is not adapted to practical commercial systems for the principal reason that the variation of capacitance is too small to effect large degrees of modulation, that is, large changes in the

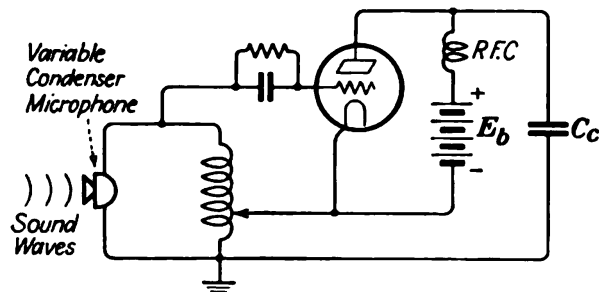


FIG. 8-5.—A fundamental FM circuit.

oscillator frequency. One significant detail to be noted, however, is the fact that if the volume of the sound impressed on the condenser microphone is increased, a greater change in the tank capacity results and causes a greater change of frequency from the rest frequency.

Since the above method of producing an FM wave is impractical, other means had to be found. One method of producing FM is by means of the Chireix or the *reactance-tube* system. Many commercial FM sets use this

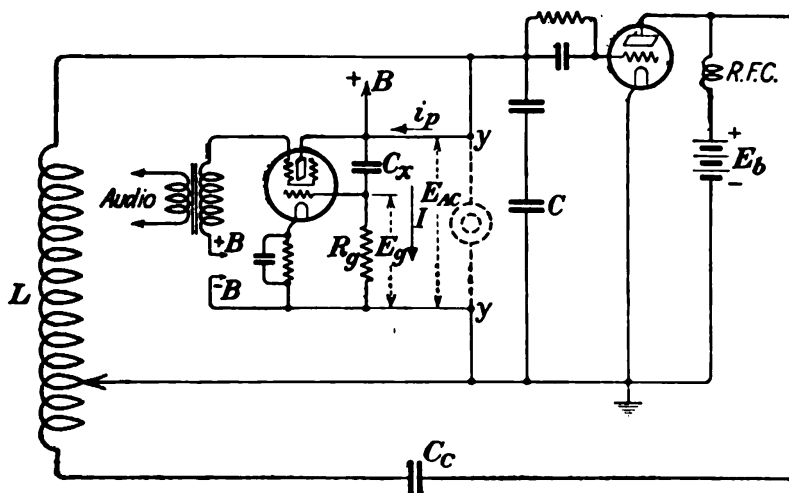


FIG. 8-6.—The Chireix, or reactance-tube, system of producing FM.

system. The principle of operation can be seen from an inspection of Fig. 8-6. In this case, an electronic circuit which behaves like a variable reactance is shunted across the main tank condenser of the oscillator. The variation of the reactance of this circuit is made to follow the variation of the frequency and amplitude of any modulating wave. This resultant variation causes a similar variation in the oscillator frequency and thus produces an FM wave. One method of introducing the audio-

modulating component is by means of the screen-grid circuit as shown in the diagram. Variation of the control-grid bias in accordance with the modulating signal is another method of injecting the audio signal into the reactance tube.

The action of the reactance-tube circuit can be studied with further reference to Fig. 8-7. The well-known principle that the current through an inductance lags the voltage that produces it by 90 degrees is illustrated in Fig. 8-7(a). In a condenser, the current through it leads the condenser voltage by 90 degrees as shown in diagram (b). The reactance-tube system is shown in diagram (c). The radio-frequency generator shown takes the place of the conventional oscillator at points $y - y$ in Fig. 8-6. The generated voltage E_{ac} is impressed across the combination of C_x and R_g in series. The reactance of C_x is purposely made very much

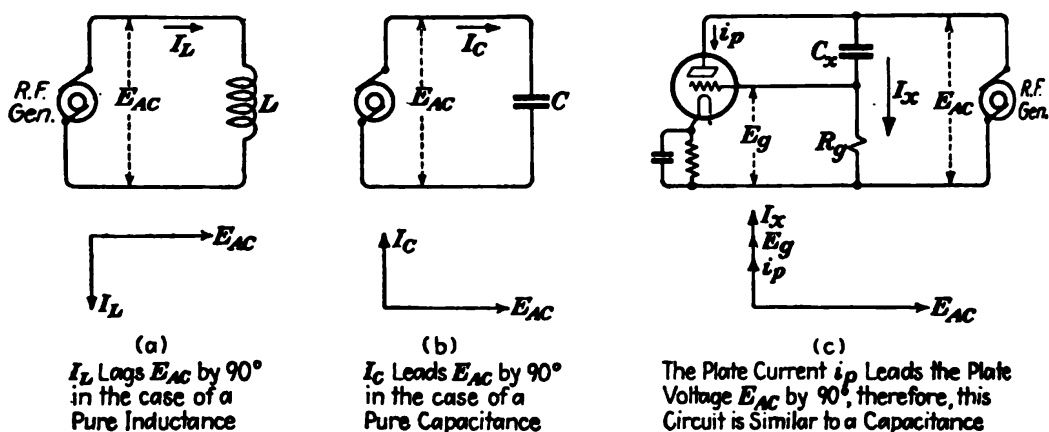


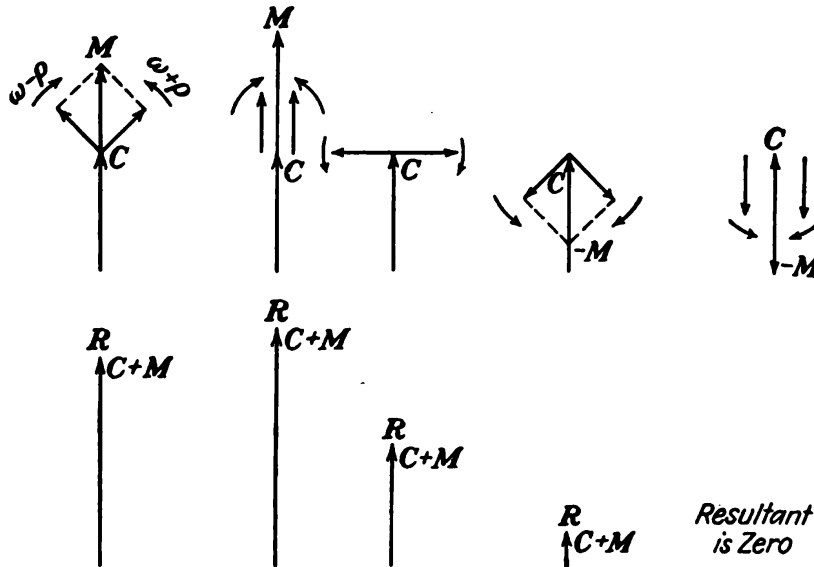
FIG. 8-7.—Vector relations of the reactance-tube circuit.

larger than R_g so that this circuit is predominantly capacitive. An inspection of Fig. 8-7(b) shows that I_x will lead the voltage E_{ac} by approximately 90 degrees. Since C_x and R_g are in series with respect to the voltage E_{ac} , the current I_x also flows through R_g . Thus the voltage E_g across R_g is in phase with the current I_x , and E_g , therefore, is also 90 degrees leading with respect to E_{ac} . This voltage E_g is applied to the grid of a vacuum tube as shown in diagram (c).

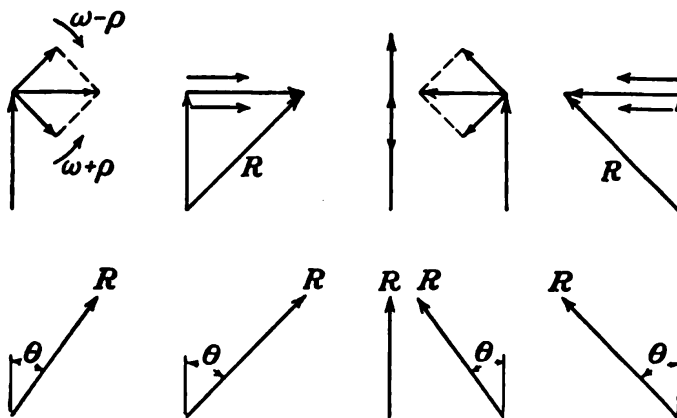
By recognizing that the plate current of a vacuum tube is in phase with the control grid voltage, it follows that i_p leads the plate voltage E_{ac} and thus the system behaves like a capacitance. Since the current flowing through a condenser with a given voltage and frequency is dependent on the value of that condenser, it is obvious that any change in current i_p will appear as a change in capacitance to the oscillator in Fig. 8-6. Hence when the plate current i_p is modulated by the action of the screen grid, the resultant variation in apparent capacity causes like changes in the oscillator frequency. In commercial FM sets, frequency excursions of as much as 10 kilocycles can be easily obtained by the reactance-tube method

the initial stage of modulation. With an oscillator frequency of the order of 5 megacycles, a multiplication of frequency of 8 to 10 is required to obtain a final frequency in the band of 40 to 50 megacycles.

8.5. The Armstrong Method.—The Armstrong method is fundamentally a phase-modulation system with the necessary modifications which yields an output wave similar in characteristics to an FM wave.



(a) For Amplitude Modulation



(b) For Frequency Modulation

FIG. 8-8.—Vector relations for carrier and sidebands for AM and FM.

remembering that the number of significant side bands of an FM wave is about numerically equal to the value of m_p [Eq. (4)] or the amount of phase deviation from the rest frequency, it is possible to employ such a value of m_p that only the first upper and the first lower side bands are important. This reminds one of the AM wave in which only two side bands are present, the upper and the lower. However, there is this difference to consider, in an AM wave the resultant of two side-band

amplitudes is everywhere in phase with the carrier and hence adds to and subtracts from the carrier amplitude; in an FM wave the resultant of the first two side bands is everywhere 90 degrees out of phase with the carrier and hence adds to and subtracts from the phase of the carrier. This is shown in Fig. 8-8. It illustrates the well-known Ferraris principle that if three frequencies are spaced equidistant in the spectrum, the outer two can be shown as vectors rotating about the stationary center vector at the same angular velocity but in opposite directions. Figure 8-8(a) shows the resultant M of the two side-band vectors alternately adding to and subtracting from the amplitude of the carrier vector C . In phase or FM, however, diagram (b) shows that the phase varies in accordance with the modulating signal.

A block diagram of the Armstrong FM system is shown in Fig. 8-9. The original oscillations are generated by means of a crystal-controlled

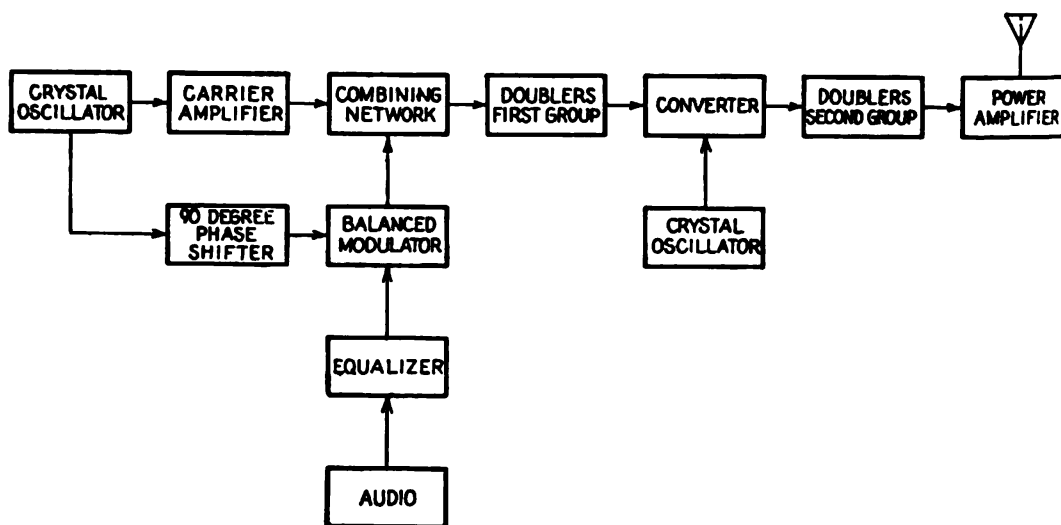


FIG. 8-9.—Block diagram of the Armstrong system of FM.

oscillator, which is one important feature of this method. This feature eliminates the necessity of a frequency-correcting circuit to compensate for changes in the oscillator frequency, since the control is by means of a crystal. (In the reactance-tube method of FM, it is necessary to use some form of correcting circuit to compensate for the variation in oscillation of the self-excited oscillator.) Part of the carrier energy is amplified further, and part is passed through a network which shifts the phase 90 degrees with respect to the carrier. This shifted frequency is then passed to a balanced modulator where modulation takes place and also where the carrier frequency is balanced out. These side bands 90 degrees from the carrier (see Fig. 8-9) are recombined with the carrier at the combining network to produce an FM wave.

It was mentioned earlier that this method is fundamentally a phase-modulation system. In phase modulation, the phase deviation m_p from the rest point is directly proportional to the modulating frequency; in

frequency modulation, m_p is inversely proportional to the modulating frequency. This can be said to be the chief difference between an FM wave and a phase-modulated wave. The necessary modification required to bring about this condition in the Armstrong system is the introduction of an audio equalizer before modulation takes place. A typical equalizer is shown in Fig. 8-10(a), and its performance characteristics are shown in Fig. 8-10(b). The required characteristic of the equalizer is that V_2 , which governs the phase deviation m_p , should be inversely proportional to the modulating frequency. Since this is the case as seen in Fig. 8-10(b), we have the condition for an FM wave as shown in Eq. (4).

In the Armstrong method only one side band is employed on each side of the carrier, therefore it is evident that no more than a maximum phase deviation m_p of 1 radian is permissible, otherwise intolerable distortion will occur. Even with a maximum initial deviation of 1 radian, it is difficult to confine the harmonic distortion at low audio frequencies to values below 5 per cent unless the value of m_p is $\frac{1}{2}$ radian or less. This maximum allowable phase deviation of $\frac{1}{2}$ radian must occur at the lowest audio frequency to be transmitted since at higher audio frequencies the phase deviation is proportionately less. For example, if the range of the modulating frequencies is 50 to 15,000 cycles per second and the value of m_p at 50 cycles is $\frac{1}{2}$ radian, the value of m_p at 15,000 cycles per second is [see Eq. (4)]:

$$m_p \text{ at } 15,000 = \frac{50}{15,000} \left(\frac{1}{2} \right) = 0.0016 \text{ radian}$$

If the final frequency deviation is required to be 75 kilocycles or 5 radians at 15,000 cycles per second, the necessary multiplication required is 5 radians divided by 0.0016, or about 3,000 times. This amount of multiplication, although requiring a large number of multiplier tubes, is possible and practical. This system requires much more multiplication than the reactance-tube method, which requires a multiplication of only eight to ten times as already mentioned.

If the oscillator frequency is to be multiplied 3,000 times, a group of approximately 12 doublers will be required. If the final frequency is in the 46-megacycle band, division of 46 megacycles by 3,000 gives an initial carrier frequency of approximately 15,000 cycles per second. Obviously

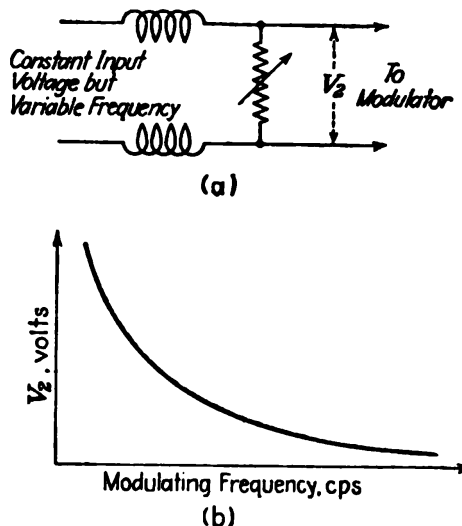


FIG. 8-10.—(a) A typical preemphasis circuit; (b) performance characteristic.

it is impractical to modulate a 15,000-cycle carrier with a 15,000-cycle audio note; hence a beating-down process is resorted to about half-way through the doublers. The choice of beat frequency is such that the remaining doublers will multiply this beat to the desired final carrier frequency. No change in the value of phase deviation m_p takes place during the beating-down process; hence none of the initial modulation is lost. After the desired multiplication is obtained, the FM wave is then amplified to the desired power.

8.6. Other Systems of FM.—Most other systems of FM are initially phase-modulated systems converted to FM as in the case of the Armstrong method. Some of these methods are listed below:

1. Cathode-ray FM generator.¹
2. Multivibrator FM generator.²
3. Off-tune tank FM generator.³
4. Variable mutual-conductance FM generator.⁴
5. Transmission-line FM generator.⁵

Still another method of generating an FM wave is that which is based on the principle that a small variable capacity shunted across a crystal can change the frequency a few cycles. The variable capacity can be simulated by the reactance-tube circuit as described earlier. The advantage of this method can be seen from the fact that the transmitter frequency is directly generated by a crystal-controlled oscillator and that modulation takes place at the crystal. Two crystals can be connected differentially to obtain large initial modulation and thus reduce the burden of large multiplication.

8.7. The Western Electric 503A-1 FM Transmitter.—A typical commercial FM broadcast transmitter is the Western Electric 503A-1 1-kw. unit. A block diagram of the 503A-1 is shown in Fig. 8-11. This transmitter makes use of the reactance-tube system of FM. It is seen that the oscillator frequency is approximately 5 megacycles, and a multiplication of eight to ten times is required to place the final carrier frequency in the FM broadcast band of 40 to 50 megacycles. A unique feature of this transmitter is the method of frequency control of the oscillator. By this method, a submultiple of the carrier frequency is beat with a reference frequency which is crystal controlled and of the same period producing two-phase currents. These currents are passed through the windings of a

¹ SHELBY, R. E., A Cathode Ray Frequency Modulation Generator, from the R.C.A. bulletin entitled "Radio at Ultra High Frequencies," April, 1940, p. 76.

² USSELMAN, G., Frequency Modulated Transmitters, U.S. Patent Serial No. 363447.

³ SEELEY, KIMBALL, and BARCO, Generation and Detection of FM Waves, *R.C.A. Review*, Vol. VI, p. 269, January 1942.

⁴ KIMBALL, C., Generator for Frequency Modulated or Phase Modulated Waves, U.S. Patent Serial No. 359314.

⁵ U.S. Patent No. 2085418.

synchronous motor which is coupled directly to a variable condenser in the oscillator tank circuit. When the transmitter frequency is correct, no currents pass through the motor and hence no correction is made. The frequency correction by this method is complete and is independent of any modulation effects.

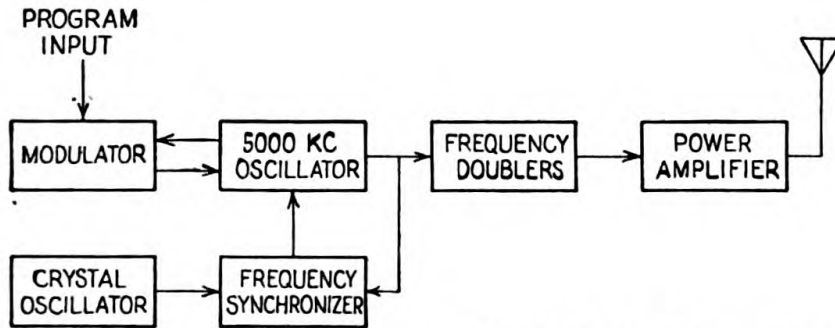


FIG. 8-11.—Block diagram of Western Electric 503A-1 FM transmitter.

A schematic diagram of the oscillator and frequency-correction circuit of this transmitter is shown in Fig. 8-12. A balanced oscillator is used to provide for wide excursions of frequency from the rest point. This type of oscillator also reduces even-order harmonics to a minimum because of

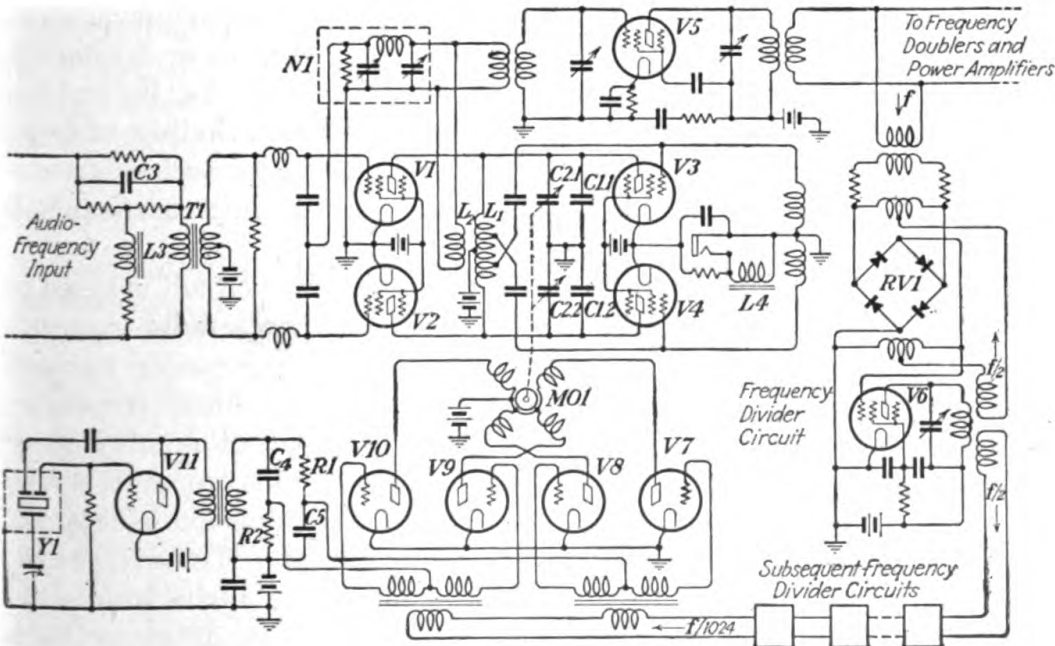


FIG. 8-12.—Oscillator and frequency-correction circuit of the Western Electric FM transmitter.

the balanced condition. Vacuum tubes V_3 and V_4 , tuning coil L_1 , and condensers C_1 and C_2 comprise the oscillator section. V_1 and V_2 are the reactance tubes which are shunted across the oscillator tank and provide the necessary variation of reactance to modulate the frequency of the oscillator. The phase-shifting network N_1 is employed to bring about

a quadrature phase relation between the oscillator tank voltage and the control grid voltage on the tubes V_1 and V_2 which is the condition required to make these tubes appear as a reactance to the oscillator. The modulating signal is also placed on the control grids of V_1 and V_2 through the audio transformer T_1 . If the oscillator voltage is not exactly 90 degrees out of phase with the grid voltage on the reactance tube, a resistive component appears in the impedance presented to the oscillator by these tubes. This resistive component can be detected as an audible sound in a headset across L_1 . A simple adjustment of the phase-shifting network N_1 until the sound in the headset is a minimum indicates that the proper quadrature relation has been obtained. This condition is essential to prevent AM of the carrier wave.

The resultant output from the balanced oscillator is an FM wave which is coupled through L_2 to a buffer stage and amplifier V_6 . From this point, the frequency is multiplied eight times by three frequency doublers and finally placed on the grids of the power-amplifier tubes. Before the FM wave is passed to the doublers, some energy is directed to the frequency dividers which not only subdivide the frequency but reduce the amount of phase shift as well. This process is carried on until a total frequency division of 1,024 is obtained. The result is a frequency of approximately 5 kilocycles with a proportionately smaller phase variation. This 5-kilocycle signal in conjunction with the reference or crystal frequency is fed to a balanced modulator consisting of V_7 , V_8 , V_9 , and V_{10} . The output currents of the modulator pass through the windings of motor MO_1 which produce a rotating magnetic field when correction is necessary. In this case, the motor armature rotates until correction is obtained.

The principle of operation of the frequency-divider circuit is based on the fact that modulation products are obtained when a radio-frequency voltage is applied to a non-linear impedance. Copper-oxide rectifiers arranged in bridge fashion are employed as the non-linear impedance indicated in the schematic diagram by RV_1 . The output circuit is tuned to a frequency which is one-half that of the input. This process is carried on in subsequent divider circuits until the required division is obtained. Unlike some other frequency-correction circuits, the Western Electric *synchronized* scheme is entirely independent of the main transmitter circuit. This fact means that no discontinuity of program service is suffered should the frequency-control circuit fail for any reason.

The frequency range of the 503A-1 transmitter is 42 to 50 megacycles and is easily capable of providing 100 per cent modulation or plus or minus 75-kilocycle swung either side of the rest frequency. •Distortion is less than two per cent at all frequencies from 30 to 15,000 cycles per second, and the frequency response is within plus or minus 1 db over the same audio range with 800 cycles per second as a reference point. The

synchronized frequency control maintains the rest frequency easily within the maximum tolerance of 2,000 cycles per second as specified by the FCC.

The power-amplifier stage tube complement consists of two Western Electric 357A vacuum tubes. This tube is a triode for general use designed especially for high radio-frequency work. The heavy leads and baseless construction provide for a minimum radio-frequency loss. Its high gain and minimum inter-electrode capacitance are additional factors which make it adaptable to high-frequency use.

Figure 8-13 shows the trend in radio-transmitter manufacture wherein all component parts are mounted on an inverted T frame for simplicity and accessibility. The covering is simply slipped over the T structure, providing protection against high voltages for the operating personnel and also a pleasing appearance. The complete unit is shown in Fig. 8-14.

8.8. Practical Considerations of FM.—In any FM set, there are three important requirements which must be met:

1. Modulation capability.
2. Reliability.
3. Frequency stability.

The transmitter must be capable of easily producing 100 per cent modulation with very low distortion from 30 cycles of 15,000 cycles. Some commercial transmitters are able to produce a frequency deviation of as much as plus or minus 600 kilocycles. Since 100 per cent modulation is equivalent to a swing of plus or minus 75 kilocycles, a practical design limit would be approximately 100 kilocycles. It is evident that absolute symmetry about the rest frequency must be obtained if no distortion is to result. That is, if an audio tone is modulating the transmitter such that 100 per cent modulation results, the transmitter frequency should vary from plus 75 kilocycles down to minus 75 kilocycles and not minus 73 or 74 kilocycles.

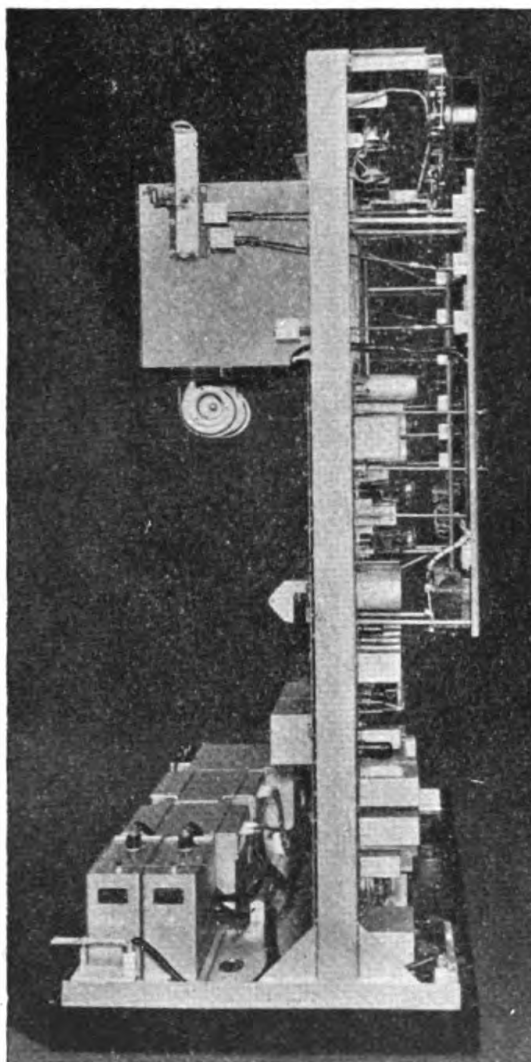


FIG. 8-13.—One-kilowatt FM broadcast transmitter, side view. (Courtesy of Western Electric Co.)

For reliability, the circuit should be free from temperature-contaminated parts as well as moving component parts. In addition, the entire transmitter must be designed such that it will respond to any and all frequencies within a channel of approximately 200 kilocycles with discrimination. Distortion in an FM transmitter is independent of the non-linearity of the vacuum tube and, therefore, any distortion

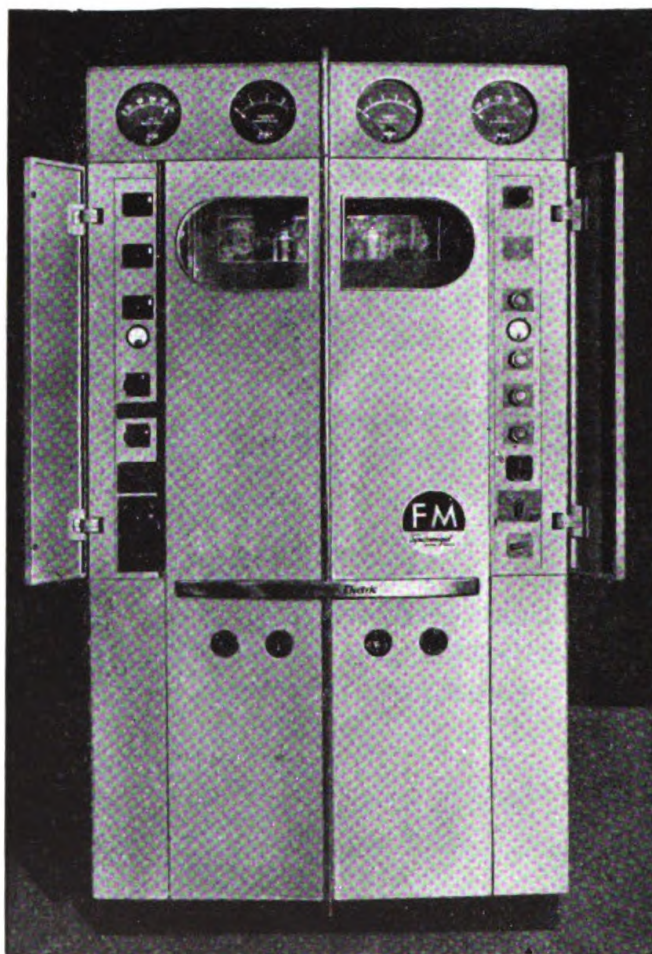


FIG. 8-14.—One-kilowatt FM broadcast transmitter, front view. (Courtesy of Western Electric Co.)

results is caused by frequency discrimination and is not due to change in amplitude.

Frequency stability is obtained by a number of different types of stabilization circuits. One of these makes use of the discriminator-slope filter. A block diagram employing this type of frequency stabilization is shown in Fig. 8-15. The principle of operation of the discriminator is based on the fact that the average direct-current discriminator output voltage is proportional to the average value of frequency impressed on it. If the oscillator frequency should drift slightly, a correction voltage appears at the output of the discriminator. This correction voltage

applied to the grids of the oscillator tubes in such manner as to cause the frequency to drift back to its assigned or station frequency. A crystal-controlled reference frequency is also used. Commercial frequency stabilizers of this type provide a correction factor of as much as 100 to 1 and can operate with negligible adverse effects over a temperature range of 50°C.

For distortion measurements, the discriminator circuit cannot be used as an FM detector because of the inherent distortion within itself. A system of detection has been described in the literature¹ which introduces negligible distortion and is an ideal means of measuring both noise and distortion. After the FM wave is detected, the various components of noise can be measured on a wave analyzer which has been found more practical than the distortion meter since each individual distortion prod-

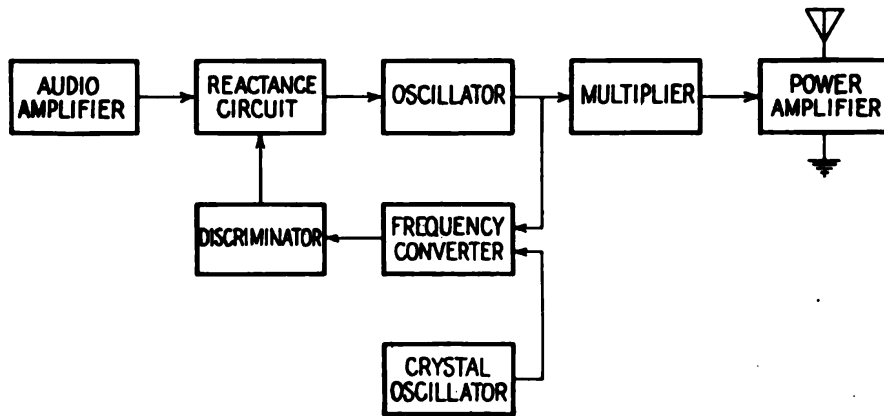


FIG. 8-15.—Frequency-modulation transmitter showing crystal-controlled frequency-stabilization circuit.

uct can be measured and analyzed. The discriminator type of detector can be employed as a modulation monitor.

There are two methods of frequency measurement:

1. Frequency division.
2. Discriminator circuit.

Frequency division is accomplished by the normal means of impressing a signal on a non-linear impedance and extracting an exact submultiple. The second method is predicated on the principle that the direct-current output voltage of a discriminator is proportional to the average frequency applied to it. Frequency monitors employ both methods.

Since an FM system is capable of easily transmitting an audio range up to 16,000 cycles, it is important that all links from the microphone to the transmitting antenna be free from discrimination against audio frequencies in this same range. This became a problem in the link between the studio and the transmitter. The best broadcast telephone

¹ U.S. Patent 2085418.

lines are satisfactory only to approximately 7,000 cycles, after which sharp cutoff takes place. For this reason, small FM transmitters or relay stations are coming into general use as a studio-transmitter link. In cases where no telephone lines are already installed between the transmitter and studio, the relay-station scheme is also of low initial cost. These FM relay stations operate at approximately 130 megacycles and above and range in power from 25 to 250 watts or more, depending on the distance and the character of terrain between the studio and the transmitter.

Highly directional transmitting and receiving antennas are employed to obtain the most satisfactory results. For example, the rhombic antenna of about $2\frac{1}{2}$ wave lengths per side can be used to obtain these conditions. At the studio, the relay-station antenna is mounted at the highest possible location and directed toward the transmitter. Distances between studio and transmitter of as much as 40 miles have been employed with completely satisfactory results under the most adverse weather conditions. This suggests that relay stations can be used for broadcast-station networks rather than telephone-line connections.

The R.M.A. transmission standard M9-218 states that "it shall be standard in television sound transmission to preemphasize the modulation at the higher frequencies according to the impedance frequency characteristic of a series inductance-resistance network having a time constant of 100 microseconds." A schematic diagram of a typical circuit known as the preemphasizer and its frequency characteristic is shown in Fig. 8-10. The preemphasis of the higher audio frequencies reduces the overall noise by approximately 10 per cent, and this justifies its use. A deemphasis circuit whose characteristic is the inverse of the preemphasizer is employed at the receiver to restore the modulation to normal levels.

One method of checking the adjustment of the deemphasis circuit in the receiver is to modulate an FM signal generator with a square wave and adjust the deemphasis circuit until a square wave is seen on a wide-band oscilloscope connected to the receiver output terminals. When this condition is obtained, the receiver deemphasis circuit behaves as the reciprocal of the preemphasis circuit at the transmitter; thus the high frequencies are reduced to normal amplitude after transmission through space at higher values which aid in the discrimination against noise. The square-wave generator has found other uses in FM among which is the examination of phase distortion due to time delay at the extremes of the audio band.

Because of the greater dependability of FM reception, this type of transmission is rapidly being extended to aviation, police, and military fields where satisfactory reception is required at all times. In this type of service where only speech and no music is transmitted, it is possible to limit the audio range to 500 to 3,000 cycles and also to employ a maximum

deviation of only 15 kilocycles. For an FM generator similar to the Armstrong system, the required multiplication would be as low as thirty times, and the band width would be reduced to 30 to 40 kilocycles under these conditions. Multiplexing of two types of signals on one carrier is also a possibility with FM. Such a system would make possible the transmitting of two sound signals on the same carrier to obtain binaural reproduction. This means that one sound channel would be placed on the carrier as FM, and the other sound channel would be placed on the carrier as AM. However, the amount of AM would be limited considerably below 100 per cent. In addition, facsimile may also be multiplexed into the FM carrier for the transmission of print and images along with sound.

8.9. Propagation of FM Waves.—Fortunately, the coverage of an FM broadcast station operating in the band of 42 to 50 megacycles is much more than can be expected from theoretical calculations. Practical measurements indicate that the area actually covered by an FM station is eight to nine times that based on the principle that the "horizon is the limit." This desirable feature is attributed largely to close-to-earth reflections due to the atmosphere. However, at these high frequencies, the attenuation due to induced ground currents is greater than ordinary broadcast frequencies. Beverage¹ indicates that the intensity of a 50-megacycle wave is inversely proportional to the square of the distance from the antenna up to the horizon; beyond the horizon, the intensity is inversely proportional to the 3.5 power of the distance.

The service range of FM stations will be greater than that obtained from the primary coverage of standard AM stations of the same power rating. The chief reason for this being the ability of FM to exclude all except the strongest signal. In addition, the coverage of FM stations will be substantially the same both day and night since the reflections from the ionosphere are few and, therefore, reception of FM waves is mainly independent of the changing height of the Heaviside layer. From the standpoint of long-distance coverage, this is a disadvantage; from the standpoint of fading-free reception, this is an advantage.

The intensity of the transmitted wave is dependent on three factors given a fixed frequency, they are (1) the distance between the transmitting and receiving antennas, (2) the height of the receiving and transmitting antennas, and (3) the radiated power. If the distance is halved, the signal is increased to four times. Doubling the transmitting antenna or the receiving antenna height increases the signal strength by 100 per cent. Twice the radiated power in the antenna increases the field strength by approximately 41 per cent. In installing FM receivers and

¹ Dr. H. H. Beverage, Vice-president in Charge of Research and Development, R.C.A. Communications, Inc.

receiving antennas, it is evident that height is an important factor. The above practical facts can be seen from Eqs. (5) and (6).

Up to the horizon,

$$\xi = \frac{Hhf \sqrt{PG}}{d^2} \quad (5)$$

Beyond the horizon,

$$\xi = \frac{Hhf \sqrt{PG}}{d^{3.5}} \quad (6)$$

where ξ = the field strength.

H = the transmitting antenna height.

h = the receiving antenna height.

f = the frequency.

P = the power.

G = the antenna gain over a half-wave dipole.

d = the distance separating the transmitting and receiving antennas.

In FM, there is a certain distance from the transmitting antenna beyond which the signal-to-noise ratio decreases sharply to the point

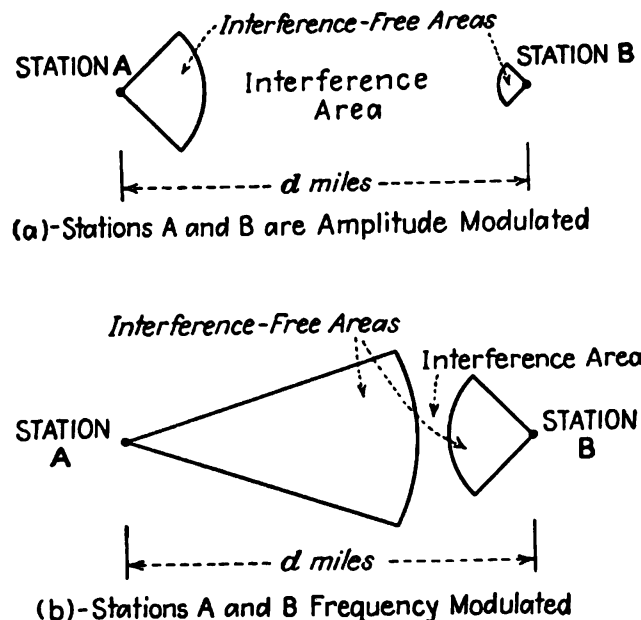


FIG. 8-16.—Interference comparison between stations A and B for both AM and FM.

where satisfactory reception is no longer possible. This is known as the "threshold" of satisfactory reception. A signal-to-noise ratio of less than 4 is considered unintelligible reception. Within the threshold area, large frequency deviations (75 kilocycles) allow for greater signal-to-noise ratio than small frequency deviations (15 kilocycles). This may be attributed to the fact that the increased signal strength as a result of a

larger percentage of modulation overwhelms the accepted noise by a large amount. Beyond the threshold area, however, the signal-to-noise ratio of an FM wave with a deviation of 15 kilocycles is greater than that of an FM wave with a deviation of 75 kilocycles. This can be understood if it is remembered that a more selective receiver can be employed to receive 15-kilocycle deviation FM; thus greater discrimination against noise is possible, and the signal-to-noise ratio surpasses that of 75-kilocycle deviation FM.

A graphical representation of the reduction of interchannel interference as a result of FM is shown in Fig. 8-16. Station *A* is three times as powerful as station *B*. Figure 8-16(a) is the result when stations *A* and *B* are both amplitude modulated. Diagram (b) shows the improvement when stations *A* and *B* are frequency modulated. Note that the useless interference area for AM is converted to an interference-free area when FM is employed. These figures do not represent the actual field distribution for the transmitters, but are used merely to compare the effects on field coverage for each type of modulation.

8.10. Polarization.—When installing an FM receiving antenna, it is important to remember that whichever polarization is employed at the transmitter this same polarization must be employed at the receiver for maximum signal pickup. The following table outlines the fundamental differences between horizontal and vertical polarization receiving antennas:

HORIZONTAL POLARIZATION	VERTICAL POLARIZATION
1. Receives signals best in only one line of direction	1. Receives signals from all directions except up and down
2. Does not receive noise or interference from one other line of direction	2. Receives interference from all directions except up and down
3. Less interference from ignition	3. Better signal pickup when aerials are less than 10 ft. above ground
4. Less interference from building reflections	4. More noise pickup since most noise is vertically polarized

Since automobile-ignition and electrical-appliance noises are vertically polarized, the horizontal antenna would receive a minimum pickup of this type of noise. At short waves, the horizontally polarized antenna has a greater signal pickup as compared with the vertically polarized antenna. For these reasons, horizontal polarization is favored for FM, although vertical polarization may be used with slightly inferior reception.

8.11. Transmitting Antennas for Use in the FM Band.—With the advent of FM, two main types of transmitting antennas were considered for practical use, the *turnstile*¹ and the *loop*² antennas. Of the two, the

¹ BROWN, GEORGE H., The Turnstile Antenna, *Electronics*, April, 1936.

² ALFORD, A., Coupled Networks in Radio Frequency Circuits, *Proc. I.R.E.*, Vol. 29, pp. 55-70, February, 1941.

turnstile type is at present in common use for the transmission of FM signals. The loop antenna is the more recent of the two and is undergoing experimental tests to determine its practicability.

The fundamental unit of the turnstile antenna is the half-wave dipole.¹ To obtain a circular field-coverage pattern, another dipole is placed at right angles to the first in the form of a cross. To conserve energy and to increase the low-angle radiation, a number of these crosses are stacked on a mounting mast one above the other. The final appearance of this arrangement suggests the reason for the name *turnstile*.

The field-strength distribution of a horizontal half-wave antenna is a figure of eight with the maximum intensity emanating along a line per-

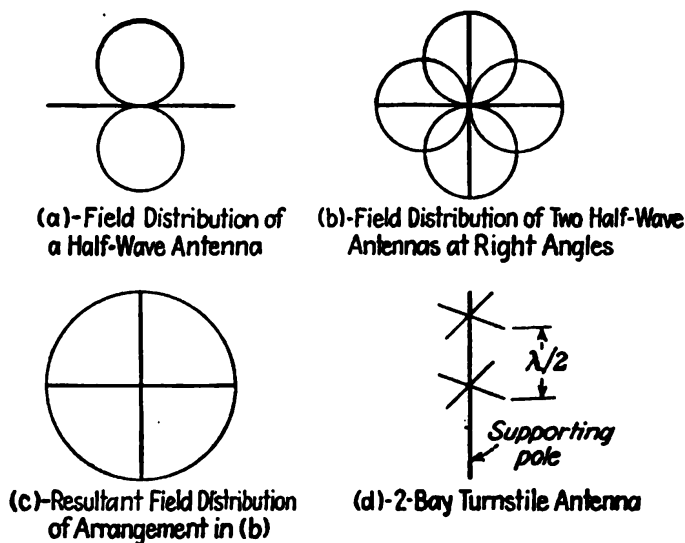


FIG. 8-17.—Evolution of the turnstile antenna.

pendicular to the axis of the antenna as seen in Fig. 8-17(a). The individual field-strength patterns of two half-wave antennas arranged at right angles in the form of a cross are shown in diagram (b) and the resultant of the two in diagram (c). Note that the field distribution is circular for the combination. This desirable condition is obtained when the currents in each of the half-wave radiators are equal and in phase quadrature. Diagram (d) illustrates a two-bay turnstile which will radiate increased signal in the horizontal plane as compared with the single bay. The increased signal as a result of adding additional bays is referred to as the "gain" over a half-wave antenna. Additional bays may be stacked on the supporting structure to obtain higher gains. However, when the overall length of the turnstile reaches three wave lengths of the operating frequency, the decreased improvement and unwieldy structure do not justify further additions.

At the present time, most of the experimental work on loop antennas is in connection with their use as a highly directive radiating system.

¹ See Sec. 7.9 for a fundamental discussion of ultra-high-frequency antennas.

Unlike the turnstile antenna, the loop antenna has its radiating element arranged in a form of a square or box. A number of these squares are stacked on a supporting mast as in the case of the turnstile antenna to confine the radiation along the surface of the earth and thus prevent the loss of energy due to high-angle radiation. The directivity of the array is governed chiefly by the distance of separation between bays.

II. THE RECEPTION OF FREQUENCY-MODULATED SIGNALS

8.12. The FM Receiver Compared with the AM Receiver.—Remembering that a frequency-modulated wave is constant in amplitude as it leaves the transmitting antenna, any variation in amplitude, as received at the receiver, must be in the form of extraneous noise and unwanted signal. This led to the most important addition to the FM set. This addition is the *limiter* stage whose function it is to remove all such extraneous amplitude variations before detection. Since one of the chief

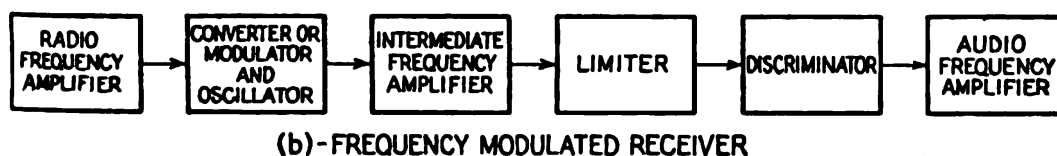
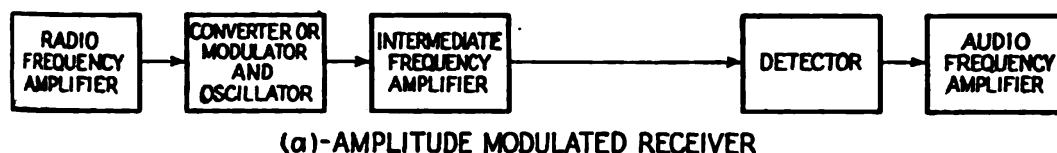


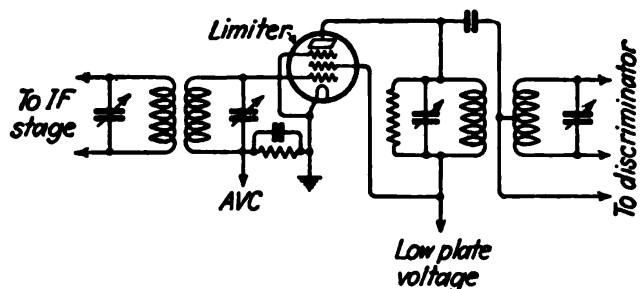
FIG. 8-18.—Comparison of FM and AM receivers.

advantages of an FM receiving set over an AM set is greatly reduced noise and extraneous interference, it is of paramount importance that the limiter stage be included and operated properly to take full advantage of FM. The location of the limiter stage in an FM set can be determined from an inspection of Fig. 8-18, which shows the chief differences between AM and FM sets.

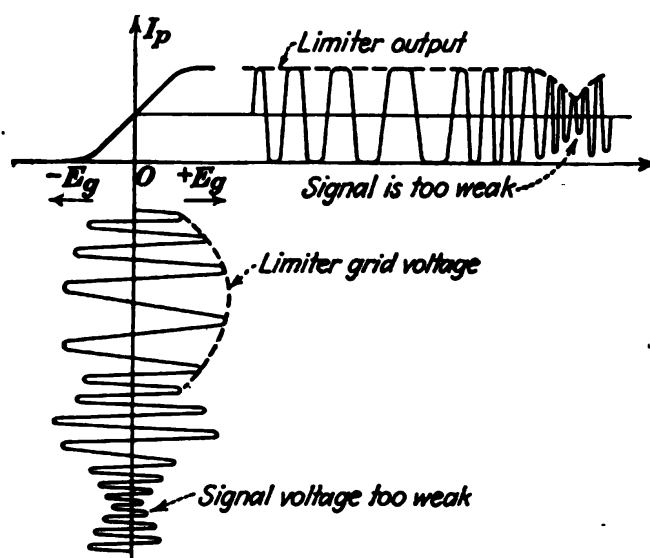
The chief substitution made in the FM set in converting from an AM set is the method of detection, since the character of an FM wave is different from that of an AM wave. This method of obtaining FM detection is accomplished by means of the *discriminator*, sometimes called a *slope filter*, which is described in a later section. Consideration must also be given to the fact that the FM receiver is operating at a higher radio frequency which calls for a slight change in the design of the radio-frequency and intermediate-frequency stages. However, it can be said that the percentage of accepted band width is approximately equal to that in the AM receiver. In addition, provision must be made to include a high-quality audio system if full advantage is to be taken of the high-fidelity feature inherent in FM. Apart from these changes and sub-

stitutions, the FM receiver is otherwise similar to the conventional AM receiver.

Outside of the receiver set itself, it is obvious that the major change in the antenna system is the physical dimensions as compared with an AM antenna, since each is called on to receive a frequency band comparatively far apart in the spectrum. The use of a horizontal-dipole antenna is commonly employed. One other distinguishing feature of the FM antenna is that it is generally higher than an AM antenna for the reasons



(a)-TYPICAL LIMITER STAGE



(b)-OUTPUT OF LIMITER FOR STRONG AND WEAK SIGNALS

FIG. 8-19.—Illustration of limiter action.

given in Section 8.9. However, the expense of installing high receiving antennas is left to the discretion of the owner who is governed by the initial expense as well as the amount of noise that can be tolerated.

8.13. The Limiter.—As already mentioned, the action of the limiter is to insure that all variations in the carrier amplitude due to noise and interference are removed and that a carrier of constant amplitude results. This is obtained by operating the limiter tube at a low plate potential such that the tube saturates easily and cutoff is produced. Figure 8-19(a) shows a typical limiter stage. A resistance is shunted across the tuned plate circuit of the limiter tube to broaden the resonance curve sufficiently

to accept the intermediate frequency when it is at the widest deviation from the rest frequency. This broad tuning can also be obtained by employing a low- Q coil. Although the voltage developed across this tank is not constant over the band width, it will be shown later that this variation is balanced out in the discriminator and no ill effects result.

The voltage on the limiter grid is large enough to cause plate saturation on the positive peaks and plate-current cutoff on the negative peaks,

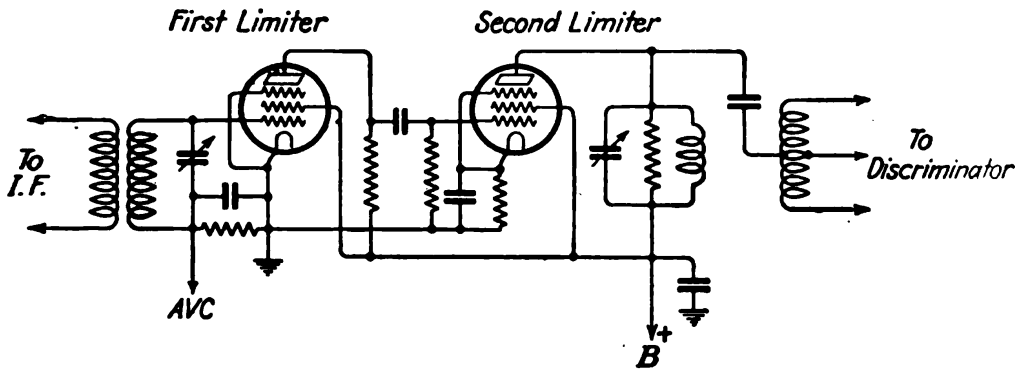


FIG. 8-20.—A double limiter circuit.

resulting in the swing of plate current or voltage between definite constant limits regardless of the variations of amplitude at the signal grid. However, the variation in frequency which represents the intelligence carried in an FM wave remains intact since the period of frequency passed by the limiter tube is independent of the curvature of the tube characteristics. This is seen in the curve in diagram (b).

If the signal voltage falls below a certain minimum, the limiter fails to take hold and cannot smooth out the variations in amplitude and all noise-discriminating advantages are lost. This suggests that the selection of the intermediate frequency and the design of the intermediate-frequency amplifier preceding the limiter should be such that high gain results, thus insuring saturation and limiter action. The limiter stage provides additional improvement in the elimination of power-supply hum which also takes the form of AM.

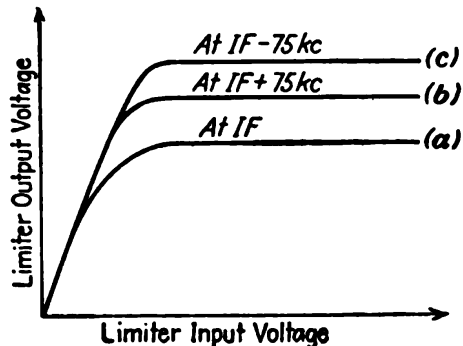


FIG. 8-21.—Limiter output curves for various input frequencies.

Vacuum tubes having a sharp cutoff are ideal limiter tubes since only a small limiter grid voltage is required to effect limiting action. In order to obtain an even sharper cutoff, it is possible to use two limiter stages in tandem called a *double limiter* as shown in Fig. 8-20. The ideal limiter stage is one whose output curve as shown in Fig. 8-21(a) does not shift when modulation takes place. Unfortunately, at other frequencies

the E_g-I_p characteristics of the tubes change somewhat as seen in (b) and (c) of Fig. 8-21. The more desirable characteristic of the double limiter over the single limiter is shown in Fig. 8-22.

Part of the limiter current is used for AVC and tuning-eye purposes. If perfect tuning and discriminator symmetry were possible, no limiter

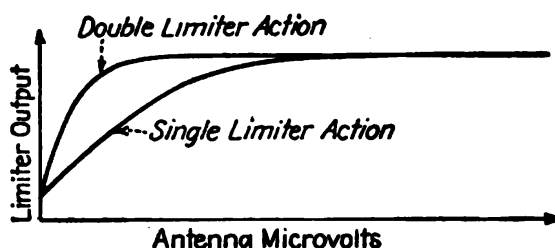
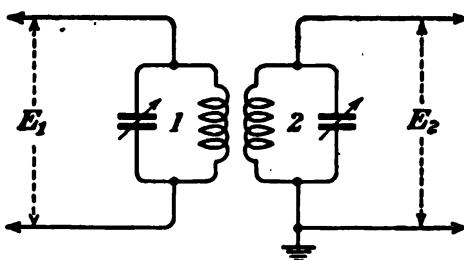


FIG. 8-22.—Limiter output characteristics.

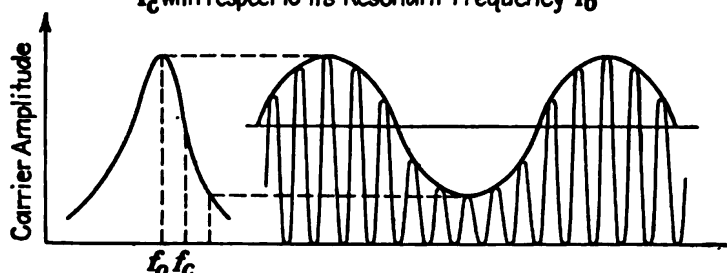
would be required. This suggests the importance of the tuning indicator as part of the FM receiver.

8.14. The Discriminator.—The function of the discriminator is to demodulate the FM wave into the audio signal which was originally superimposed on the carrier. Since a loud-speaker or headset is sensitive



(a)-Tank Circuit 1 (very broad) is tuned to f_c (Carrier Frequency)

Tank Circuit 2 (very sharp) is mistuned at f_c with respect to its Resonant Frequency f_0



(b)-Output Voltage of an Off-Tuned Tank Circuit

FIG. 8-23.—Detecting FM waves by means of sharp-resonance circuits.

to audio frequency and amplitude variation, the demodulated signal must also be of this form as in AM sets. The simplest form of circuit which can be used to demodulate an FM wave is a resonant circuit sufficiently sharp so that the frequency variations detune the circuit on one side of resonance. The effect is that as shown in Fig. 8-23(b). As the frequency

increases from the resonant frequency f_0 in the direction of f_c , the amplitude of the carrier voltage E_2 across the tuned circuit decreases. The variation of this voltage is dependent on the variation of the frequency, that is, a carrier modulated with a 400-cycle sine wave causes a sine-wave variation of voltage E_2 across the off-tune tank circuit.

This principle can be carried one step further if a second off-tune circuit is coupled to the primary. This circuit, however, has its resonant frequency on the other side of the carrier f_c . The two secondary tanks can then be connected so that their output voltages are additive, thus yielding a voltage variation of about twice that of a single tuned secondary.

Because of the initial cost and the number of adjustments, the above method of FM detection has been superseded by a circuit of the type shown in Fig. 8-24. The basic principle of operation revolves about the

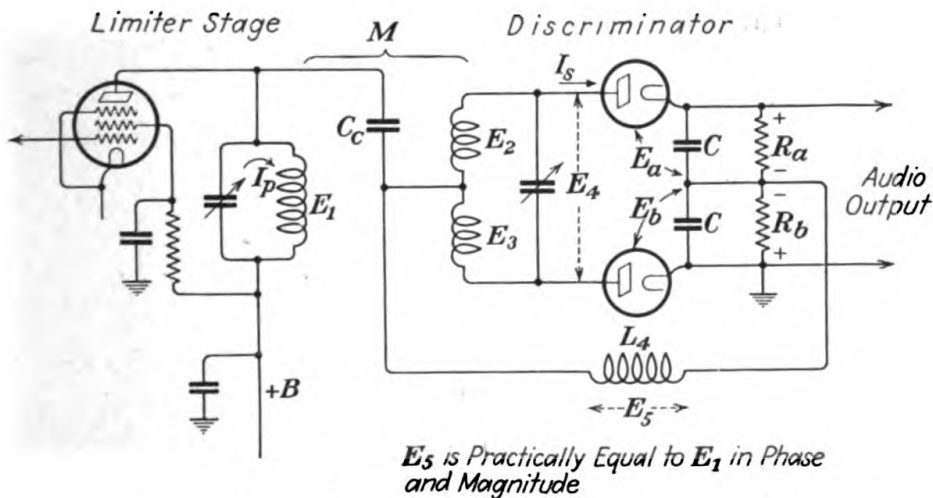


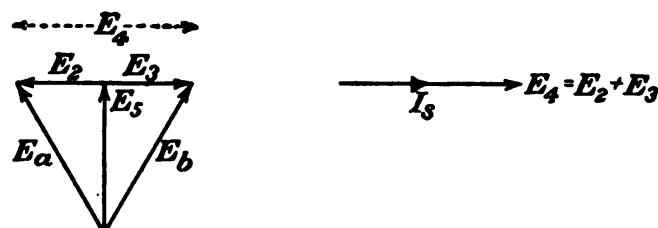
FIG. 8-24.—The center-tapped secondary discriminator.

fact that the voltages E_a and E_b across the diodes rise and fall differentially as the frequency in the tuned secondary varies above and below the rest frequency f_c . Since this method of reducing an FM carrier to an audio signal is rather interesting, a further description of the circuit operation is presented here. From coupled-circuit theory, we have the fact that the voltage induced in the secondary to two coupled circuits is 90 degrees out of phase with the primary current as seen in Eq. (7).

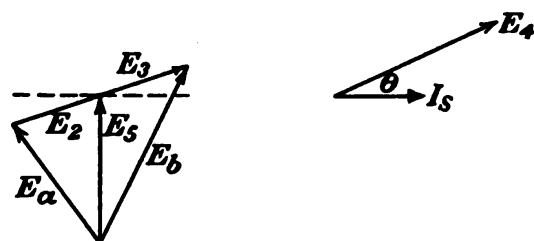
$$E_s = -j\omega MI_p \quad (7)$$

Since the primary circuit is tuned to resonance, the impedance in it consists of a pure resistance; hence E_1 is in phase with the primary current I_p . Therefore, E_1 is also 90 degrees out of phase with the secondary voltage. As seen in Fig. 8-25(a), the secondary voltage is made up of two equal voltages E_2 and E_3 , the sum of which is E_4 , the total secondary voltage. The voltage E_1 is introduced into the secondary as E_5 at the

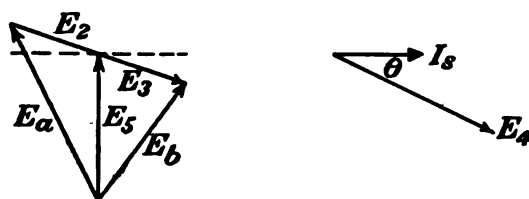
mid-point of the secondary transformer through the blocking condenser C_c . Practically all this voltage appears across the inductance L_4 , since the impedance of C_c and C combined is purposely made small compared with the impedance of L_4 . Since this voltage E_5 is equal in magnitude and phase with E_1 , it follows that E_5 is also 90 degrees away from E_4 . This relation is shown graphically in Fig. 8-25(a). It is also evident that the vector sum of E_5 and E_2 is E_a and the vector sum of E_5 and E_3 is E_b . As will be shown later, it is the voltages E_a and E_b which vary differen-



(a)-At Resonance



(b)-Below Resonance



(c)-Above Resonance

FIG. 8-25.—Vector relations of the center-tapped secondary type of discriminator.

tially in magnitude when the frequency varies above and below the rest or *no-modulation frequency*.

At the resonant frequency, the secondary circuit is tuned to resonance and the conditions shown in Fig. 8-25(a) prevail. Under these conditions, the in-tune secondary voltage E_4 is exactly in quadrature with E_5 . The voltages E_a and E_b are equal, and because of the method of connection, the voltages across R_a and R_b exactly balance out and no audio output appears. Below resonance, the circuit becomes inductive and the voltage advances or leads the current. From diagram (b) it can be seen that the vector addition of E_5 and E_3 and of E_5 and E_2 no longer yield equal voltages. This results in an increase in E_b and a simultaneous decrease in E_a , therefore, the voltage across R_b is greater than that across R_a and a

resultant voltage appears in the audio output. Above resonance, the secondary circuit becomes capacitive and E_4 lags as in diagram (c). The action is similar to the below-resonance case except that E_a increases while E_b decreases. Since these voltages are unlike, an output difference voltage will appear. If the carrier is frequency modulated with a sine wave of audio frequency, the discriminator output will be a sine-wave voltage of that same audio frequency.

The proper adjustment of the discriminator can be checked by tuning the discriminator secondary transformer until no audio output is obtained when the frequency is steady at the rest point. The diode circuits are

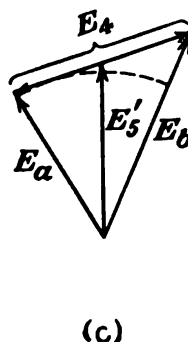
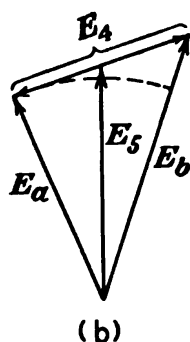
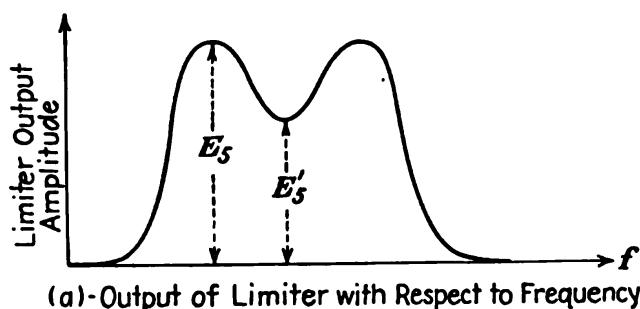


FIG. 8-26.—How the variable output of the limiter caused by frequency changes tends to balance out.

generally combined into one tube, since this has been found practical. The limiter tuned circuit is magnetically coupled to the discriminator tuned circuit, and it can be expected that the output of the limiter circuit may be a double-humped characteristic as shown in Fig. 8-26(a). However, as already mentioned, this variation from the output of the limiter tends to balance out so that the discriminator characteristic is symmetrical as shown in Fig. 8-27. For a given phase shift of E_4 , and a value of E_s in Fig. 8-26(b) and E'_s in Fig. 8-26(c), it can be seen that regardless of the value of E_s the difference between E_a and E_b remains substantially the same. Since the output is proportional to the magnitude of this difference, and not to the absolute value of E_a and E_b , the discriminator characteristic is linear over the desired range. Figure 8-27 also shows that the

amplitude of the audio output is proportional to the maximum frequency deviation from the intermediate frequency F .

If the receiver is very badly tuned, the operating point may be shifted to the left of line AB or to the right of line CD . This results in a reduction of output by one-half, or 6 db, indicating the importance of tuning eyes and tuning meters in FM sets. If the receiver is slightly off tune, the discriminator output curve or the S curve is unsymmetrical about the intermediate carrier frequency F , and amplitude-distortion results.

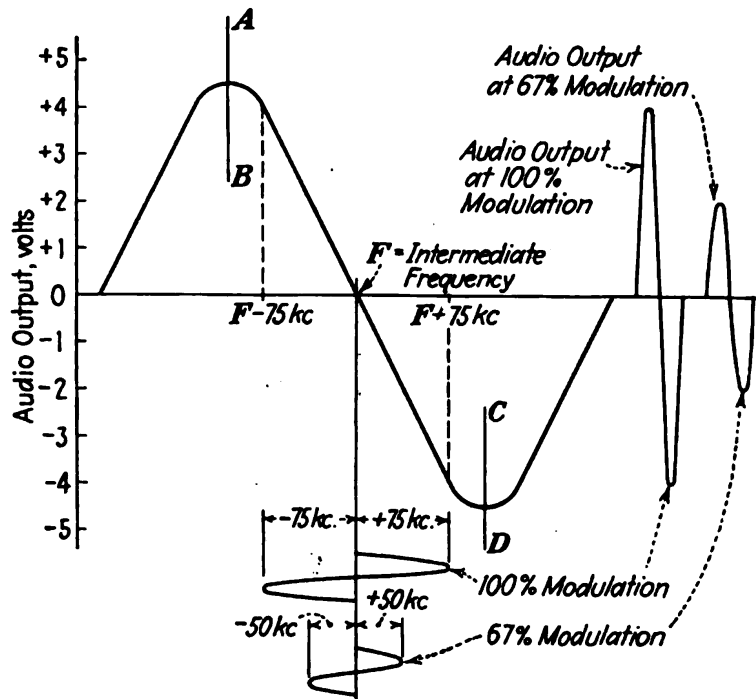


FIG. 8-27.—The discriminator S characteristic.

8.15. Radio-frequency Circuits in FM Receivers.—In circuit structure, the *FM* radio-frequency stages are similar to the conventional *AM* superheterodyne, the chief difference being in the nature of the signal received. For this reason, radio-frequency circuits of the FM receiver require special attention in consideration of the high frequencies involved.

In order to prevent undue radio-frequency loss owing to the dielectric absorption, it is common practice to employ a balanced low-impedance transmission line from the antenna to the receiver-input terminals in order to allow a maximum transfer of energy. FM transmission lines of the less expensive type are rubber-insulated twisted-pair lines, the loss of which depends mainly on the quality of insulating rubber.

The importance of obtaining a maximum radio-frequency voltage gain before the mixer or modulator tube is realized when it is remembered that the signal-to-hiss ratio at low signal levels is small. The gain of the first radio-frequency stage must be sufficient to allow the signal to ride easily above the noise level of the converter stage. The sensitivity of receivers

is limited only by the tube-noise level. Modern receivers are designed for a sensitivity of 1 to 3 μv per meter, and an amplification of approximately 1,000,000 times is required.

Due to the fact that the FM range of 42 to 50 megacycles is a fairly small percentage of the radio spectrum compared with the AM band, radio-frequency amplifier design problems are simplified from the standpoint of band passing. A band width at least 200 kilocycles wide is required to be amplified indiscriminately by the radio-frequency stages to avoid distortion. Broadly tuned radio-frequency circuits can be obtained if necessary by shunting a loading resistance across the radio-frequency tank circuits or by using low- Q coils.

The grid circuit of the first stage should have a high L/C ratio in order to maintain a high-impedance input. This suggests the use of inductance tuning to replace the capacity tuning at the lower frequencies. Inductance tuning can be accomplished by a number of methods, but the two methods most commonly used are the magnetic-core tuning and coil-switching tuning. These methods are also less expensive than a variable condenser of very small capacity. In addition to high grid-circuit impedance of the first radio-frequency stage, it is important to choose a tube with a high gain per milliamperere of space current to improve the signal-to-hiss ratio.

In modern combination AM-FM sets, single channels are employed for both the AM and the FM signal. Switching from one band to the other is accomplished by conventional means. In some of the less expensive models, the first radio-frequency amplifier tube is omitted and the antenna feeds directly into the mixer tube. In some of the more expensive sets, two separate channels, one for AM and the other for FM, are employed. A typical commercial home receiver is the Stromberg-Carlson 935 series shown in Fig. 8-28. This is a three-gang set providing reception for both AM and FM and employs the Armstrong wide-swing FM system.

The oscillator and converter circuits are quite the same as in the AM receivers, but it might be mentioned that the same grid of the converter tube may be used to receive the signal voltage and the oscillator voltage. This arrangement tends to reduce the mixer noise.

The intermediate-frequency amplifiers must be of sufficiently high gain to insure saturation of the limiter at all times. As seen in Fig. 8-28, some manufacturers employ the AM and FM intermediate-frequency transformers in series. There is no reaction of one on the other since both are parallel circuits, and the AM intermediate-frequency transformer is almost a short circuit to the FM intermediate frequency, and vice versa. Since it is imperative that the limiter be fully saturated at all times, it is to be expected that more intermediate-frequency stages will be built into FM sets than in the AM sets. Intermediate-frequency stages in FM sets

must be especially designed to maintain approximately the same time constants over the range of frequencies to be received, otherwise discrimination against certain frequencies will result and thus produce distortion.

The values of the intermediate frequency in FM sets range from 4 to 12 megacycles. An intermediate frequency of less than 4 megacycles cannot be used if image interference is to be eliminated. To eliminate interference as a result of two strong local stations on the same carrier frequency, the intermediate frequency should be 8 megacycles or more, since the range of the FM broadcast band from 42 to 50 megacycles is 8 megacycles in width. Values of intermediate frequencies of 8.25 and 11.5 megacycles have been tried, but the responses at these frequencies are low and frequency stability suffers. An intermediate frequency of approximately 4.3 megacycles seems to give best results.

8.16. Servicing FM Receivers.—The equipment required to service any FM receiver is the same as that used for AM receivers with one or two additions. The method of handling this equipment, therefore, will be somewhat similar to AM receiver service equipment. The FM service laboratory should have the following main pieces of equipment:

- a. An FM signal generator with wide band-sweep circuit.
- b. An electronic direct-current vacuum-tube voltmeter.
- c. A conventional oscillograph.

As in AM receivers, stray responses are likely to be picked up by FM sets. This fact emphasizes that the FM receiver should be one operating on the superheterodyne principle to provide maximum selectivity in view of the relatively small band width of 42 to 50 megacycles to be received. Because of the many types of extraneous responses, FM receivers require additional care and skill in alignment and servicing. Some of these extraneous signals are image interference, signals from two transmitting stations the difference of whose frequency is the receiver intermediate frequency, direct intermediate-frequency pickup, signal-intermediate-frequency, oscillator-harmonic products, and half intermediate-frequency image interference.

As already mentioned, the image response is reduced by selecting some odd value of intermediate-frequency just above the minimum value of 4 megacycles. In the case of spurious responses resulting from two strong local FM stations separated in frequency by the receiver intermediate-frequency, difficulty is likely to be encountered over the entire band. Unfortunately, exact receiver alignment will not alleviate this condition. With an intermediate-frequency below 8 megacycles, the only remaining solution is in the antenna which can be oriented to avoid pickup from at least one of these local stations. If the intermediate frequency is chosen above 8 megacycles to eliminate this type of interference, then the Q of the

coils must be approximately twice as good as those used for an intermediate frequency of 4.3 megacycles, if the same gain is to be had.

The design of the receiver oscillator must be such as to allow a minimum generation of harmonics, otherwise oscillator harmonics and undesired signals in the antenna may combine to produce the intermediate frequency of the set which leads to objectionable whistles and interference.

The problem of regeneration must be seriously considered as is the case in AM receivers. Because of the higher frequency and higher field strength in the receiver, because of the high gain of the intermediate-frequency amplifier, most regeneration difficulties arise in these stages. All necessary precautions must be taken to prevent this by employing high-quality component parts and intelligent arrangement of these parts, as well as proper dressing of leads and good by-passing and shielding. One of the effects of regeneration is to peak the intermediate-frequency response curves to such a degree that serious amplitude distortion may result at high percentages of modulation.

An FM receiver in general will have a very high hiss level when tuned to certain stations. This is due to the mixer hiss level and the high amplification of the intermediate-frequency stages and also to the ability of the better-than-average audio system to pass high hiss frequencies. The origination of this hiss is mainly in the mixer tube as is the case in an AM set, since amplification is not the prime purpose of the mixer tube. Every effort should be made to obtain as large a signal as possible at the grid of the first radio-frequency stage to alleviate this trouble. Antenna orientation, balanced low-impedance, low-loss transmission lines, and short solid grounds are factors to be considered in an attempt to attain this ideal condition. Vacuum tubes having a high gain per milliampere of space current should be employed as mixers to reduce this hiss level. Notwithstanding any receiver defects, a high hiss level indicates that the signal input at the receiver input terminal is too low owing to a poor antenna system or to the fact that the receiver is beyond the threshold area. When judging the merits of an FM receiver, therefore, caution must be exercised to the extent that the receiver signal input is at least equal to the manufacturer's minimum requirements.

The use of automatic-volume-control (AVC) circuits is not so important in the FM receiver, since this action is taken care of somewhat by the action of the limiter in maintaining a constant level output. In addition, the intermediate-frequency stages may be made to provide partial limiting action to reduce the burden on the limiter stage. For this reason, the limiter current may be employed to operate tuning indicators and, if AVC is required, to operate as the correcting voltage.

A signal-tracer is well adapted for determining the shape of radio-frequency response characteristics. With this piece of apparatus, it is possible to obtain a plot of the response characteristic of the radio-

frequency, intermediate-frequency, and limiter stages. For example, the limiter output characteristic as shown in Fig. 8-26(a) can be obtained with the signal tracer.

Alignment of the FM receiver should begin with alignment of the intermediate-frequency stages and in particular the intermediate-frequency stage preceding the limiter. The intermediate-frequency from the signal generator is impressed on the grid of the stage preceding the limiter, and adjustment for resonance is made. It is important to remember that the limiter generally draws grid current when operating properly and, therefore, the value of the intermediate-frequency voltage impressed on the grid must be sufficiently high to insure limiter saturation, otherwise it is possible to tune intermediate-frequency transformer to a false peak because of an unloading effect when the limiter grid draws no current. Similar adjustments are made on the remaining intermediate-frequency stages working in the direction of the antenna.

Discriminator alignment follows the alignment of the intermediate-frequency amplifier stages. It is necessary to adjust the discriminator properly if full advantage is to be taken of the FM high-fidelity characteristics. With the intermediate-frequency injected into the receiver at some convenient point, a vacuum-tube voltmeter is connected across the output of the discriminator and the discriminator tuned circuit is adjusted until the direct-current output voltage is zero. This indicates that the voltages developed across R_a and R_b in Fig. 8-24 are exactly equal in amplitude and opposite in phase. When modulation takes place, these voltages are no longer equal and the difference represents the useful audio output. Therefore, the direct-current voltmeter across the output of the discriminator cannot be used as a dynamic check of the adjustment; that is, when the signal is modulated the direct-current voltmeter does not afford an accurate check. However, it is possible to make a plot of the discriminator S curve to determine its symmetry by using a signal generator whose frequency output can be adjusted in steps of 10 to 20 kilocycles from about 100 kilocycles on the low side of the intermediate frequency to 100 kilocycles on the high side. The readings on the direct-current voltmeter are recorded for each frequency and plotted.

Summarizing the above adjustment and alignment of FM receivers, and referring to the Stromberg-Carlson schematic diagram in Fig. 8-28 as a concrete example, the steps are as follows:

For intermediate-frequency adjustments:

1. Connect the vacuum-tube voltmeter between ground and one side of the limiter-grid resistor.
2. Connect the ground terminal of a wide band-sweep signal (plus or minus 300 kilocycles) to the ground terminal of the second intermediate-frequency tube socket.
3. Introduce a signal of 4.3 megacycles to the grid of the second intermediate-frequency tube through a suitable condenser (about 0.1 mf).

4. Tune the secondary (L_{42}) and the primary (L_{41}) of the third intermediate-frequency transformer for a maximum reading.
5. Repeat operations 2 and 3 on the first intermediate-frequency tube socket.
6. Repeat operation 4 on the second intermediate-frequency transformer (L_{39} and L_{40}).
7. Repeat operations 2 and 3 on the mixer tube.
8. Repeat operation 4 on the first intermediate-frequency transformer (L_{37} and L_{38}).

For discriminator adjustments:

1. Inject the unmodulated receiver intermediate frequency into the input terminals of the first intermediate-frequency tube being sure that sufficient generator output voltage is applied to insure good limiter action.
2. With the electronic voltmeter connected across one-half of the discriminator output, tune the primary of the discriminator transformer for a maximum reading.
3. Connect the electronic voltmeter across the entire discriminator output, and adjust the secondary of the discriminator transformer for zero reading.

A more thorough adjustment of the discriminator includes the operation of checking the symmetry of the S curve about the rest frequency. This is done by applying frequencies in steps of 10 or 20 kilocycles above and below intermediate frequency and noting the reading of the electronic direct-current voltmeter across the discriminator output. Plotting these values against the corresponding frequency readings will show the linearity and shape of the discriminator characteristics. Should this curve be unsymmetrical or non-linear or both, serious amplitude distortion will result. A slight readjustment of the discriminator primary transformer should be made and the entire test run over again until the desired S curve is obtained.

With regard to the adjustment of the radio-frequency stages, suffice it to say that the operation is similar to that of AM receivers. Since the FM broadcast band is a relatively narrow one, commercial FM receivers do not have critical tracking problems as in the AM sets.

8.17. FM Receiving Antennas.—From the standpoint of physical size, the FM antenna is smaller in construction than the AM antenna. However, an inspection of Eq. (5) shows the importance of installing the antenna as high as possible above ground. The amount of signal pickup in the FM antenna must be sufficiently high to insure complete limiter action, otherwise distortion and noise will result.

An ordinary antenna for the AM broadcast band can be used to pick up FM signals, but it is not so well adapted since this antenna is constructed so that its physical dimensions are commensurate with the wavelength to be received. On the other hand, the dimensions of a half-wave antenna in the 50-megacycle region is only about 10 ft. Further, for an AM antenna, the lead-in wires from the antenna consist generally of a single wire feed line. Operating at the high FM frequencies, however, this type of lead-in is not permissible because of the attendant high radio-frequency loss.

In general, there are three main types of antennas used for high-frequency reception; namely, half-wave dipoles, loops, and tilted wires. The latter two offer no appreciable advantages over the half-wave dipole and because of their highly directional characteristics are not so practical for the reception of FM broadcast stations.

The half-wave dipole is commonly used because of its simple construction and relatively large signal pickup with a given physical size. This antenna usually consists of two conductors placed end to end and

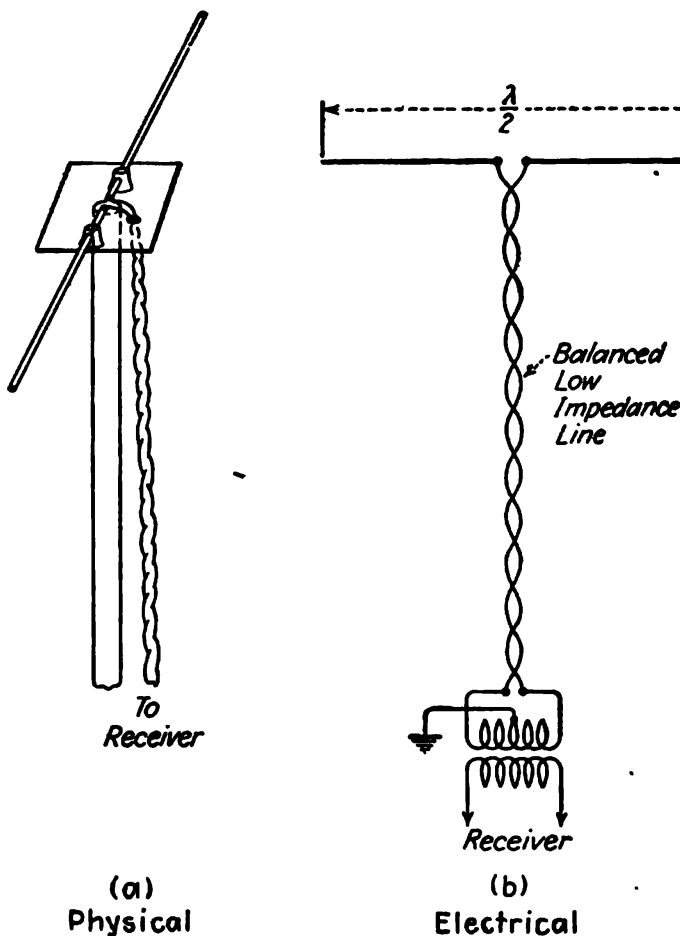


FIG. 8-29.—A half-wave dipole receiving antenna.

each approximately one-quarter wave length long, as shown in Fig. 8-29(a). The feed-in line is then connected in series with the antenna at the center opening, as shown in Fig. 8-29(b). This arrangement allows a minimum of disturbance to the symmetrical field pattern of a half-wave antenna (see Fig. 8-17). A single dipole whose physical dimensions are calculated on the basis of the center frequency of the band to be received will generally prove satisfactory over a band width of 10 to 15 megacycles in the 50-megacycle region. The following formula can be used to find the dimension of one conductor of a dipole antenna for receiver use:

$$\text{Length of each dipole conductor (feet)} = \frac{246}{\text{frequency (Mc.)}} \quad (8)$$

To obtain greater directivity and increased signal pickup, a continuous conductor slightly longer than the dipole can be placed $\frac{1}{10}$ to $\frac{1}{4}$ wave length behind the dipole as a reflector. This arrangement, shown in Fig. 8-30(a), will increase the signal roughly 40 to 50 per cent, although the antenna is made more frequency selective. In television, for example, where the reception of a wide range of frequencies is necessary, it is desirable to maintain a broad antenna frequency-selectivity characteristic. The FM broadcast band of 42 to 50 megacycles is relatively narrow, and dipole elements of about 5.3 ft. apiece will provide satisfactory reception over this entire range.

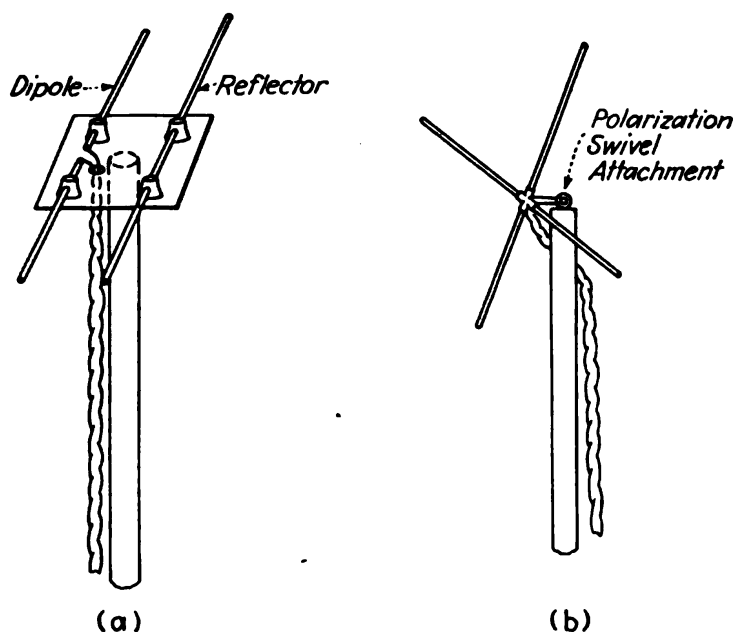


FIG. 8-30.—The dipole with reflector and the adjustable cross antenna.

Some manufacturers equip receiving antennas with a polarization attachment to allow the antenna to be tilted at an angle that will provide the maximum signal pickup. When the receiver is far away from the transmitting station, increased signal pickup can be obtained by adding a second vertical dipole to the horizontal dipole as shown in Fig. 8-30(b). For further pickup, this "cross" arrangement can be tilted until maximum signal with least noise is received. This allows the reception of electromagnetic waves both vertically and horizontally polarized. For combination AM-FM receivers, it is possible to use the same antenna lead-in wire by resorting to the arrangement shown in Fig. 8-31. A few turns of the antenna wire around one of the insulators before connection to either one of the elements of the dipole will prevent the reaction of the AM antenna on the dipole.

The impedance of the dipole antenna in the 50-megacycle region is roughly 100 to 120 ohms. Ordinary rubber-insulated twisted-pair transmission lines have a characteristic impedance of approximately the

same range which allows reasonably close matching without the necessity of resorting to matching transformers. However, for the best possible results, matching of impedance must be carried out conscientiously if a maximum transfer of energy is to be had. It is also important that a high-quality transmission line be used since the difference may result in an increase of signal of as much as 100 per cent at the receiver input terminals.

When installing the antenna, several locations should be tried, all as high as possible in order to get away from building reflection effects.

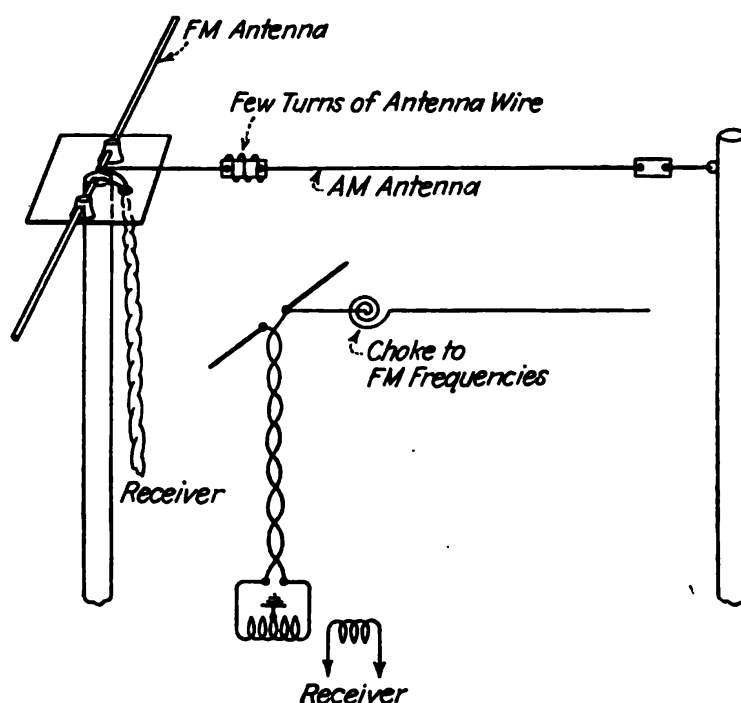


FIG. 8-31.—Combination AM-FM antenna with equivalent electrical diagram.

Rotate the dipole until the average reception of all stations to be received is best. At distant locations, it may be necessary to tilt the dipole from a horizontal position to an angle of 45 degrees or so.

The antenna should be installed as far away as possible from thoroughfares where automobile-ignition and electric-train interference is high. The transmission line should be as short as possible, but remember to install the antenna as high as possible before any attempt is made to shorten the transmission line. This is necessary because increase in antenna height is more beneficial than the harmful effect of the attendant increase in transmission-line lengths. The lead-in shield should be grounded at the receiver end to a low-resistance ground such as a water pipe, a copper network ground, or the equivalent. A number of ground locations should also be tried until a maximum signal is heard with a minimum of noise.

PARTS OF STROMBERG-CARLSON AM-FM RADIO RECEIVER 935 SERIES
(See Fig. 8-28)

Circuit designation	Capacitors	Circuit designation	Resistors	Circuit designation	Coils, transformers, and speakers
C-116.....	10 mmf.	R-27, 28, 29, 30, 73.....	10,000 ohm	L-46.....	Discriminator choke
C-77, 78, 99.....	0.1 mf.	R-1, 2, 3.....	Voltage divider	L-31.....	Heater choke coil
C-70, 71, 73, 74.....	0.04 mf.	R-12, 13, 14, 15, 16, 17.....	1,000 ohm	L-32.....	Coil link
C-72, 76, 79.....	0.05 mf.				
C-68, 75.....	0.02 mf.	R-7, 78.....	10 ohm	L-37, 38.....	1st I. F. transformer, FM
C-58, 59.....	250 mmf.	R-8.....	22 ohm	L-39, 40.....	2d I. F. transformer, FM
C-109, 110.....	200 mmf.	R-9.....	150 ohm	L-41, 42.....	3d I. F. transformer, FM
C-93, 94.....	Dual 0.05 mf.	R-10, 11.....	120 ohm	L-43, 44, 45.....	Discriminator, I. F. transformer, FM
C-45, 48, 59, 50, 51, 57, 106.....	50 mmf.	R-18.....	1,200 ohm	L-33, 34.....	1st I. F. transformer, AM
C-52, 53.....	50 mmf.	R-20, 21.....	1,500 ohm	L-35, 36.....	2d I. F. transformer, AM
C-54.....	100 mmf.	R-72.....	2,200 ohm	L-16, 17.....	RF coil, A band
RC-1.....	Compensator, A band	R-22.....	6,800 ohm	L-18, 19.....	Oscillator coil, A band
C-112.....	300 mmf.	R-23, 34, 25, 26.....	4,700 ohm	L-20, 21.....	Antenna coil, short wave
C-114, 115.....	75 mmf.	R-31, 19.....	15,000 ohm	L-22.....	RF coil, short wave
C-60, 61, 62, 92.....	500 mmf.	R-32.....	22,000 ohm	L-23, 24, 25.....	Oscillator coil, short wave
C-47.....	15 mmf.	R-33, 34, 35.....	47,000 ohm	L-26, 27.....	Antenna coil, FM
C-90, 95, 104.....	0.25 mf.	R-36.....	68,000 ohm	L-28.....	RF coil, FM
C-69.....	0.005 mf.	R-37.....	0.56 megohm	L-29, 30.....	Oscillator coil, FM
C-63.....	0.002 mf.	R-38.....	82,000 megohm	L-1, 2, 3, 4, 5, 6.....	60-cycle power transformer
C-19.....	Aligning capacitor, 1 unit	R-40, 43, 44, 45, 46, 47, 66, 67.....	0.1 megohm		Speaker
C-56.....	400 mmf.				Cone for P-33963 speaker
RC-3.....	Compensator short wave	R-48, 49.....	0.15 megohm	L-47, 48, 49.....	Output transformer
C-55.....	120 mmf.	R-50, 51, 52, 53, 54.....	0.27 megohm	L-7.....	B choke
C-81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 97, 98.....	Dual 0.01 mf.	R-55, 56, 57, 58, 59.....	0.47 megohm	L-25.....	Filter assembly low bass
C-64, 65, 66, 67, 91, 96.....	0.01 mf.	R-61, 62, 39, 64, 65, 71, 41, 60.....	1 megohm	L-14, 15.....	Antenna coil, A band
C-18.....	Aligning, 1 unit				
RC-4, 5.....	Compensator, A band	R-63.....	0.22 megohm		
C-39, 40, 41, 42, 43, 44.....	Variable	R-68, 69, 70, 42.....	1.5 megohm		
RC-2.....	Compensator, FM band	R-75.....	5,600 ohm		
C-1, 107.....	Electrolytic	R-74.....	10,000 ohm		
C-101, 103.....	100 mmf.				
C-100, 102.....	605 mmf.				
C-105.....	410 mmf.				
C-2, 3, 4, 5.....	Electrolytic				
C-6, 7, 8, 9.....	Electrolytic				
C-22.....	86 mmf.				
C-20, 21.....	Aligning, 2 unit				
C-10, 11, 12, 13—C-14, 15, 16, 17.....	Aligning, 4 unit				

CHAPTER 9

AVIATION RADIO COMMUNICATION

Radio communication is an integral part of modern aviation. Without radio and the quick communication and aviation aids it supplies, aviation as we know it could not exist. As the flying range of the modern aircraft increases, the demands upon the radio-communication system controlling these flights also increases. Therefore, the trend has been toward more powerful, wider coverage radio-communication equipment with facilities for quick operational changes from one frequency channel to another.

I. TRANSMITTERS

9.1 Multi-frequency Ground-station Transmitter. WESTERN ELECTRIC RADIO TRANSMITTER No. 14C. *a. General Description.*—This transmitter is a multi-frequency crystal-controlled radiotelephone and radiotelegraph transmitter which may be preadjusted to any of 10 frequencies within the range 2 to 18.1 megacycles. It will deliver a carrier power to 400 watts between 2 and 12 megacycles and 300 watts between 12 and 18.1 megacycles, with capability of substantially complete modulation for telephone or modulated *CW* transmission. The operating frequency is selected by operating a single-digit telephone dial located on the front panel or a similar dial in a remote location. A front view of this transmitter is shown in Fig. 9-1.

Three methods are available for controlling the carrier:

1. Push-button control.
2. Key carrier control.
3. Voice-operated control.

Various types of services may be used, such as push-button operation on telephony only, that is, local control; *C-W* telegraphy and push-button operation on telephony, permitting keying for *CW* with break-in as a feature at all hand-keying speeds; and *CW* and *MCW* (modulated continuous waves) keyed tone-controlled telegraphy and voice-operated control of the carrier on telephony.

The output circuit of the No. 14C transmitter is designed to operate into a 500-ohm load. Arrangements are made to connect the output of one or more channels directly to the 500-ohm point on one or more half-wave antennas or, through the use of suitable coupling units, to one or more 500-ohm two-wire balanced transmission lines such as would be

required by directional antenna. In addition to these possible terminations, one or more channels may be connected directly to a tuning unit which provides correct coupling to one or two suitable vertical wire antennas. Any combination of the foregoing antenna arrangements may be used.

A schematic diagram of the radio-frequency circuits of this transmitter is shown in Fig. 9-2. When MCW telegraph or telephone trans-

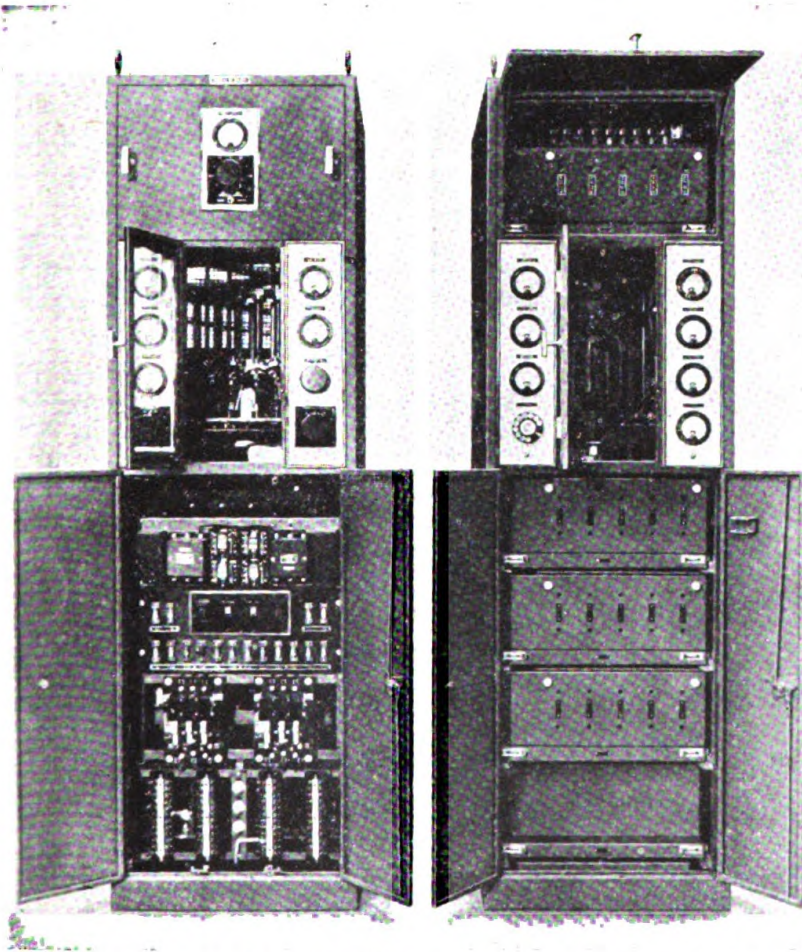


FIG. 9-1.—Western Electric radiotelephone transmitter and rectifier.

mission is employed, modulation is applied to the plate and screen grid of the modulating amplifier, which immediately precedes the final- or power-amplifier stage.

The plate circuit of the oscillator is close coupled to the grid of the first buffer stage through the stopping condenser C_5 . A specially designed (No. 11 type) tuning unit, which is plugged in the first buffer chassis, serves as a complete tuned circuit for the first buffer stage when switch D_6 is closed. If this stage is to function as an amplifier, a tuning unit is used which tunes to the crystal frequency. The remaining stages are similarly coupled as shown in the diagram.

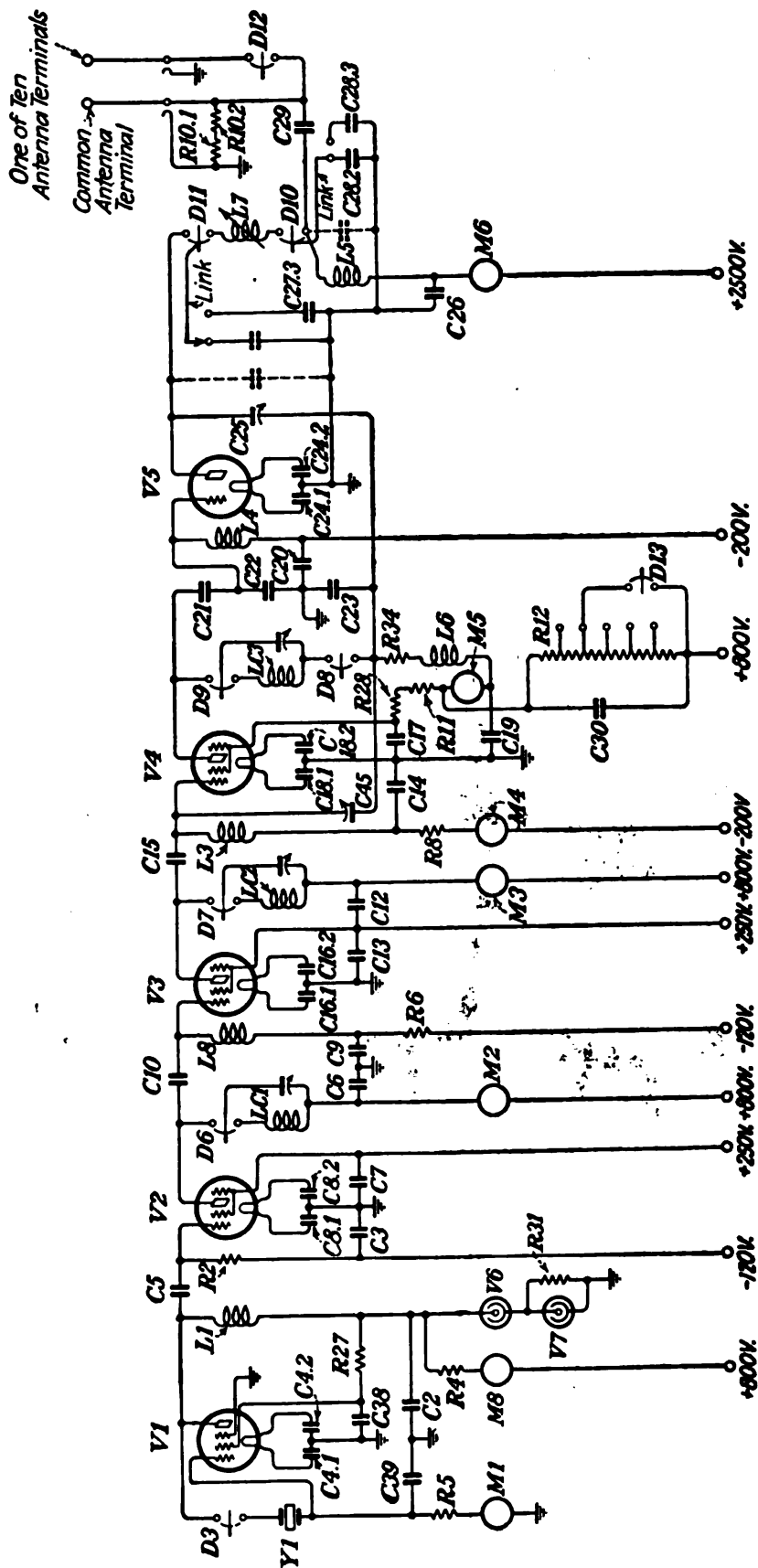


FIG. 9-2.—Schematic diagram of radio-frequency circuits of 14C transmitter.

Of special interest is the neutralizing condenser C_{45} , which, contrary to usual practice, is used to neutralize the screen-grid tube V_4 , balancing out the residual capacity of the tube. Excitation to the grid of the power-amplifier tube is supplied from the junction of condensers C_{21} and C_{22} .

Closing switch D_{13} short-circuits a portion of resistor R_{12} and leaves the correct amount of resistance in the plate supply to the modulating amplifier tube. The power-amplifier stage has its circuit completed by an appropriate tuning coil which is adjusted to tune this circuit properly when switches D_{10} and D_{11} are closed.

b. Sequence of Relay Operation in Transmitter.—In the following explanation, the symbol R denotes that the item is located in the rectifier, the symbol T denotes transmitter. This explanation may be followed by referring to the complete schematic diagram of the transmitter and its associated rectifier, type 9C, as shown in Fig. 9-3.

As soon as the main power-supply switch D_1R is closed, transformer T_5R is energized and furnishes 48 volts direct current (negative ground) from the rectifier X_1R to be used for the microphone supply and, in the manner indicated below, for relay operation when any number is dialed.

As a typical case, let it be supposed that channel 2 is dialed (see Figs. 9-3 and 9-4). As the dial is allowed to return to its normal position, the following sequence of events takes place at the dial contacts: "first close," "first open," "second close," "second open." The instant of "first close" energizes slow-release relay S_3T (from ground on the dial contact D_1T to 48 volts on terminal $15T$ via transfer contacts of $S_{13}T$ in its normal position and relay-protecting rectifier X_4T) and simultaneously pulls up the armature of selector S_1T , thereby stretching its return spring. The instant of "first open" releases the selector armature, which is then pulled back by the spring. This causes the brushes to rotate to position 1, S_3T remains operated owing to its slow release characteristic, and no further action takes place.

The next instant is that of the "second close" when selector S_1T and relay S_3T again simultaneously receive a pulse of energy which pulls S_1T up (S_3T is already up and thus remains unaltered in this position). The next "second open" period follows immediately; the selector moves to position 2, and nothing further happens until S_3T releases at the end of its slow-release period (about $\frac{1}{4}$ sec.). When S_3T releases, the following sequence of events takes place: 48 volts is supplied through the lower armature of S_3T .

a. Through the third selector bank to energize relays S_6T in the transmitter and S_3R (via terminal $21R$ and relay protecting rectifier X_3R) in the rectifier.

b. Through the fourth selector bank, via break contact $S_{13}T$ in its normal position, to energize latching relay $S_{7,1}T$.

c. Through the normally closed contacts of time-delay relay $S_{11}T$ to upper normally open contact of S_6T .

As soon as S_5T has operated (its holding circuit, described under item (3) above, keeps it energized), two results follow:

a. Holding current at 48 volts direct-current is supplied to the No. 9C rectifier at terminal 21R to hold relay S_3R (see below) while and after the selector S_1T notches itself back to normal as hereafter described. (Relay S_3R is later released by the operation of relay S_4R as described in the following section.)

b. The lower armature of S_5T completes the circuit through elevator magnet S_6T which is actuated and moves elevator 2 to its UP position and also starts the ventilating fan which is parallel connected across S_6T . The 220 volts alternating current across terminals 9T and 10T leading from phases 1 and 3 of the rectifier operates elevator magnet S_6T .

When S_5T is actuated, it mechanically operates switch $D_{15}T$ in series with the coil of relay $S_{13}T$. Relay $S_{13}T$ then operates, and as a result the following simultaneous events take place:

1. The holding current to $S_{7.2}T$ is broken at the normally closed upper contacts of $S_{13}T$. ($S_{7.2}T$ is mechanically held in place owing to the force exerted on No. 2 push rod.)

2. A circuit to selector S_1T is completed which causes the selector mechanism automatically to notch itself back to its normal position. This circuit is from ground via the upper normally open contacts of $S_{13}T$, the upper contacts of relay S_5T , the breaking switch associated with and actuated by S_1T , No. 1 selector bank to the winding of S_1T . The other end of this winding goes to the positive 48-volt supply at terminal 15T.

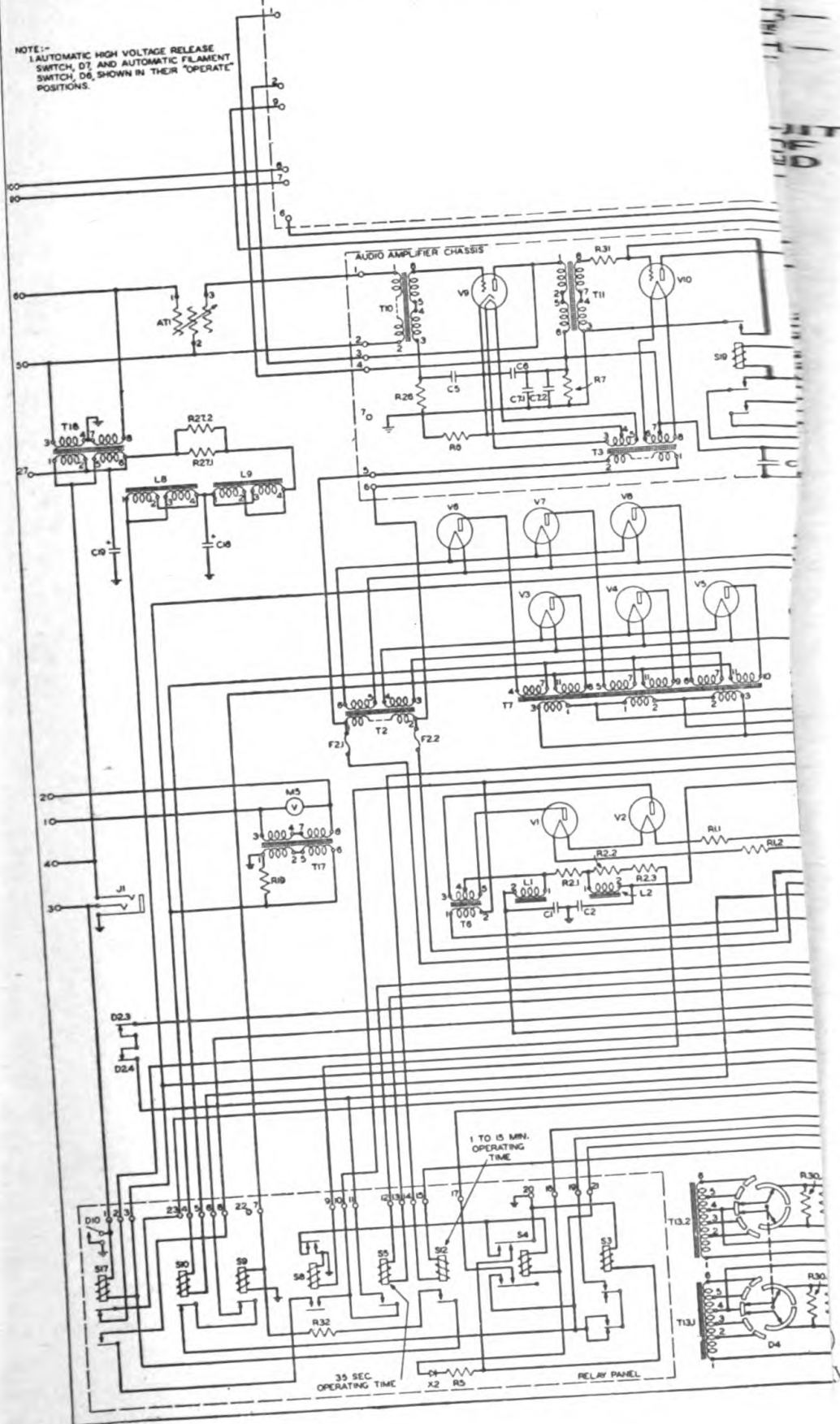
3. The transfer contacts of $S_{13}T$ prevent S_3T from receiving any pulse as the selector notches back to its normal position.

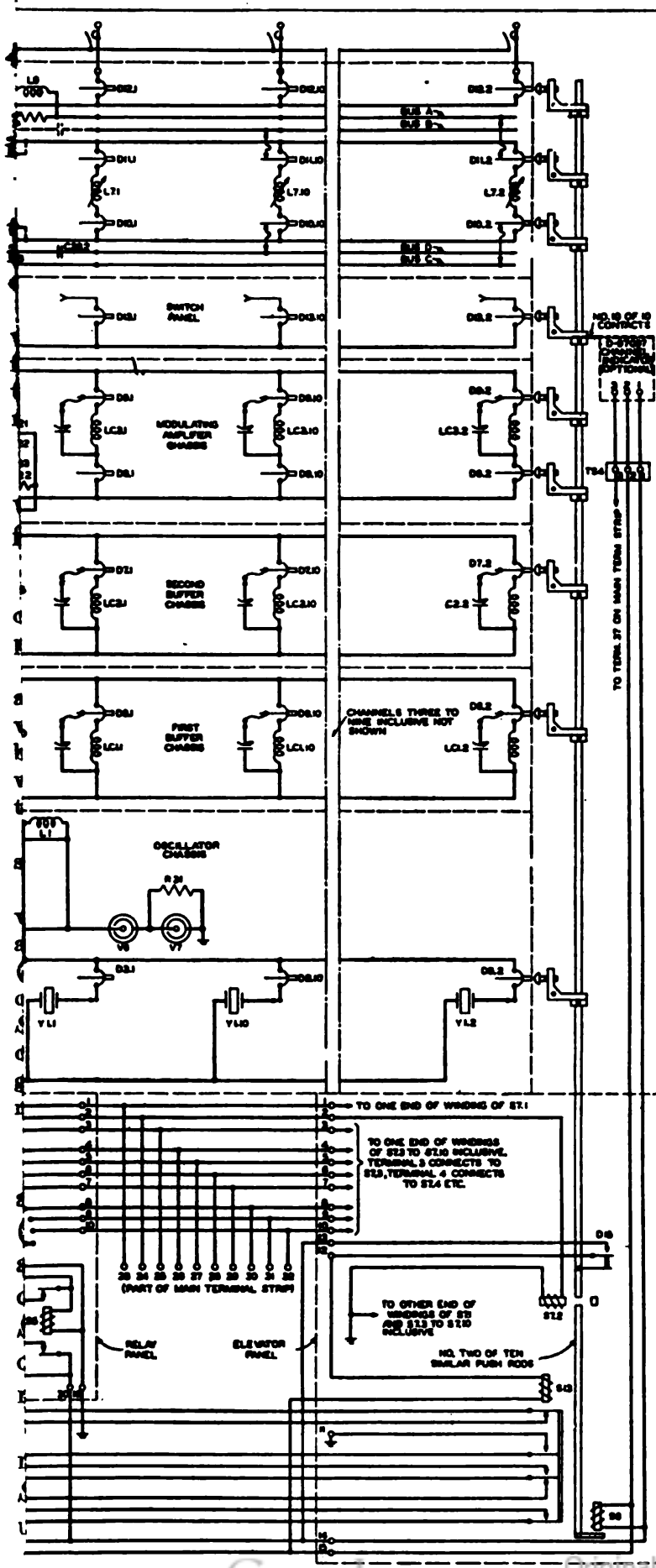
4. The lower pair of normally open contacts of $S_{13}T$ close and constitute the high-voltage contactor (S_2R) interlock. Thus the high-voltage contactor cannot be actuated until after S_5T has completed the setting up of one of the 10 channels. (The high-voltage contactor circuit when *finally* completed is from fuse $F_{10.2}R$ via contacts of overload relays S_9R and $S_{10}R$, lower normally open contacts of relay S_4R , $S_{13}T$ "interlock" contacts, winding S_2R , lower normally open contacts of carrier control relay $S_{17}R$, lower normally open contacts of relay S_3R , contacts of relay S_4R , gate switches $D_{2.4}R$, $D_{2.3}R$, $D_{2.1}R$, $D_{2.2}R$, $D_{14.5}T$, $D_{14.4}T$, $D_{14.3}T$, $D_{14.2}T$, $D_{14.1}T$, terminal 9T to fuse $F_{10.1}R$.)

Sequence of Operation of Control Relays (No. 9C Rectifier).—As soon as 48 volts direct current is supplied to terminal 21 of the No. 9C rectifier (see Fig. 9-3), relay S_3R is energized through copper oxide rectifier X_2R and resistance R_5R and is subsequently held energized by the operation of relay S_5T . When this relay pulls up, it energizes filament contactor S_1R by completing the following circuit: from fuse $F_{10.1}R$ through winding of relay S_1R , through contacts of relay S_3R , through contacts of overload relays $S_{10}R$ and S_9R to fuse $F_{10.2}R$.

When filament contactor S_1R pulls up, it short-circuits the contacts of relay S_3R through its own back contacts. Thus the holding circuit of S_1R is made independent of the operation of relay S_3R , but remains under control of the overload relays S_9R and $S_{10}R$. The operation of

NOTE:-
1. AUTOMATIC HIGH VOLTAGE RELEASE
SWITCH, D7, AND AUTOMATIC FLAMENT
SWITCH, D8, SHOWN IN THEIR "OPERATE"
POSITIONS.





S_1R heats all vacuum-tube filaments by simultaneously energizing transformers T_1R (all radio and C bias rectifier-tube filaments), T_2R (all high-

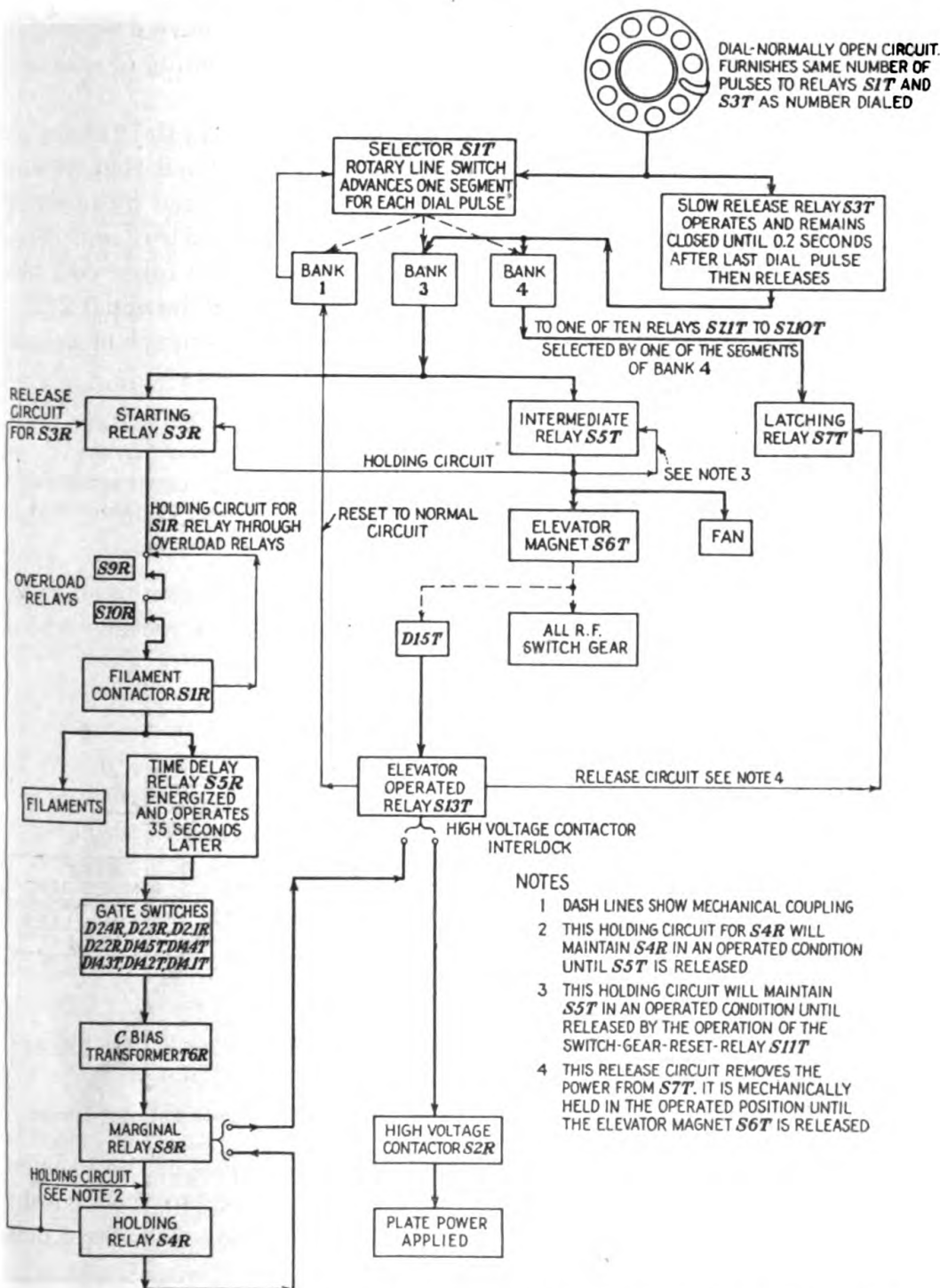


FIG. 9-4.—Functional diagram showing sequence of operation of power control relays.

voltage rectifier-tube filaments) and T_3R (both audio-tube filaments). Simultaneously with the energizing of transformer T_1R , time-delay relay

accidental contact with high voltage. The locations of the gate switches are as follows:

- $D_{2.1}$ —Glass panel tube door of No. 9C rectifier.
- $D_{2.2}$ —Front panel of No. 15C control unit.
- $D_{2.3}$ } —Two doors at the bottom of the No. 9C rectifier.
- $D_{2.4}$ }
- $D_{14.5}$ —Glass panel tube door of No. 14C radio transmitter.
- $D_{14.4}$ —Removable cover plate on power-amplifier chassis.
- $D_{14.3}$ —Removable cover plate on modulating-amplifier chassis.
- $D_{14.2}$ —Removable cover plate on second buffer chassis.
- $D_{14.1}$ —Removable cover plate on first buffer chassis.

In addition to this protection, the act of removing any one chassis breaks the gate-switch circuit and automatically removes both the grid bias and high voltage from all circuits.

All pretuning adjustments are made with a Western Electric No. 705A tool inserted through circular holes in the grounded front cover plates of the various chassis. Since these cover plates must be securely locked in place in order to have power applied to the set (necessary for tuning), it is impossible, unwittingly, to perform the tuning operations in a manner hazardous to the operating personnel.

As an additional precaution, there is provided on the switch panel of the No. 9C rectifier an ON-OFF toggle switch marked HIGH VOLTAGE. Opening this switch prevents all high voltage and grid bias from coming on, even though all gate switches are closed. *It should always be turned off when any work is being done inside either unit.* Opening this high-voltage switch insures that an accidental closing of a gate switch will not result in any high voltage being present within either unit.

Protection to Apparatus.—Two self-restoring overload relays S_8R and $S_{10}R$ are provided to protect the vacuum tubes against accidental overloads. These relays are located in the return circuits of the 800- and 2,500-volt power supplies, respectively, and when energized by an amount of current appreciably in excess of that required for normal operation of the transmitting equipment operate to disable all power supply circuits, with the exception of the 48-volt supply. Redialing is necessary to restore the set to normal operation after an overload has tripped either of these relays.

d. Care and Maintenance.—The transmitting equipment herein described has been so designed that routine maintenance will assure regularity of service and high-quality performance. In the following paragraphs are outlined the principal points to which care should be given and the nature of the operations required to give continuity of service.

All vacuum tubes have limited life, and unless their ultimate failure is anticipated interruption of service may result. The best assurance

against interruption of service is to keep careful records of hours of service and meter readings. The tube-life record should indicate the date of installation and the elapsed hours of service during which plate voltage is applied on each vacuum tube in the equipment. The record of meter readings should be made periodically, perhaps once a day, on each operating frequency and should show the reading of each meter in the set. The following list of vacuum tubes used in the equipment together with symptoms of faulty performance (as indicated by meter readings) has been prepared in order that the operator may be warned in advance of tube failure.

Use	Code No.	Aging effects noticeable
Oscillator.....	307A	Decreased modulating-amplifier grid current
1st buffer.....	282A	Decreased modulating-amplifier grid current
2d buffer.....	282A	Decreased modulating-amplifier grid current
Modulating amplifier.....	282A	Increased modulating-amplifier plate current Decreased power amplifier plate current Decreased antenna current Decreased modulation level for same input
Power amplifier.....	251A	Decreased power amplifier plate current Decreased antenna current Insufficient increase in antenna current during modulation
2d audio amplifier.....	284D	Decreased modulation level for same input
1st audio amplifier.....	272A	Decreased modulation level for same input Decreased sensitivity of voice-control equipment for same input
1st carrier control amplifier ($V_{11}CU$).	205D	Decreased sensitivity of voice-control equipment for same input
2d carrier control amplifier ($V_{12}CU$).	205D	Decreased carrier-control relay current for same input and same setting of sensitivity control
Bias rectifier tube (V_1KP)..	RCA80	Slight modulating-amplifier plate current for telegraph key in UP position
2,500-volt rectifier tubes...	249B	Decreased plate voltage at normal line voltage particularly under load
800-volt rectifier tubes.....	249B	Decreased plate voltage at normal line voltage particularly under load
200-volt rectifier tubes.....	249B	Decreased bias voltage at normal line voltage
Oscillator voltage regulator tubes (V_6, V_7).....	RCA874	Failure to show blue glow when operating

As will be observed, there is in general no clean-cut, positive way of determining when a tube has arrived at the end of its useful life, since symptoms of approaching tube failure are often associated with other tubes. There are, however, certain symptoms that are peculiar to each tube and which only a careful study of the meter-reading record will

reveal. The final test is, of course, replacement of tubes suspected of faulty performance by new tubes *one at a time*.

e. Auxiliary Equipment.—The following optional pieces of equipment are available and may be used in conjunction with the No. 14C radio transmitter to enhance its usefulness in certain installations.

No. 100 Type Coupling Unit. Used in conjunction with two-wire 500-ohm balanced antenna systems. One of these units is required for each channel so terminated.

No. 10B Tuning Unit. Used in conjunction with one or two vertical wire antennas. Only one of these units required for any number of channels up to the full complement of 10.

No. 14A Control Unit. Used for controlling the No. 14C radio transmitter from a technical operator's position.

No. D-97098 Selective Dialing Unit. Used for dialing the No. 14C radio transmitter over the speech input circuit from a remote-control point.

No. D-97097 Channel Indicator Panel. Used to provide a visual indication of the channel dialed. The channel indicating meter associated with this panel may be located at a remote-control point. •

No. D-97104 Rectifier. Used to provide plate power to the second carrier control tube of the No. 15CU control unit in installations which do not have available a 180-volt supply from an associated radio receiver.

9.2. Converting a Phone Transmitter for CW.—In order to use a radio-telephone transmitter for telegraphy, it is necessary to convert it

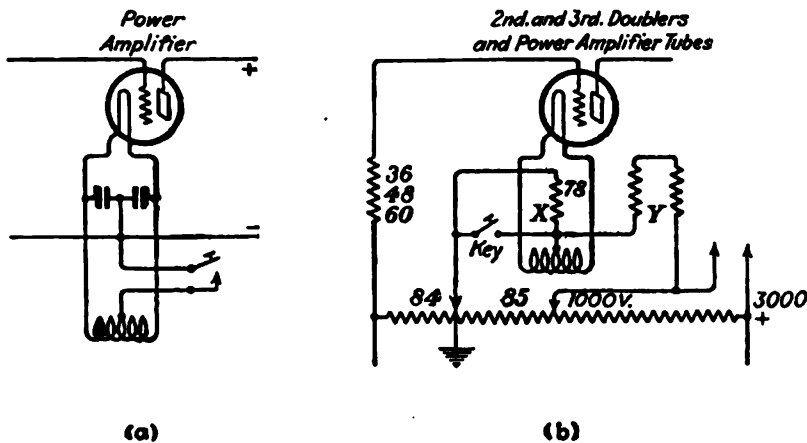


FIG. 9-6.—Methods of keying a transmitter.

for *CW* or *ICW*. Such a conversion is simply a problem of keying the transmitter so that the carrier wave may be interrupted. There are a number of methods of doing this, and the particular one to adapt would depend on the power of the transmitter and the equipment available.

To convert a low-power transmitter, not over 500 watts, for *CW*, the simple method of interrupting the negative high-voltage return to filament on the power amplifier at the point of lowest potential, which would be close to the ground connection, would be satisfactory. Such a scheme is shown in Fig. 9-6(a).

If a power higher than 500 watts is involved, the conversion is not so simple. However, the simplest way of keying such a transmitter would be to insert a resistor in series with the negative high-voltage return to filament of such a value that the voltage developed across it would be sufficient to bias the amplifier to cutoff. The key could then be arranged to short-circuit this resistance when keying as shown in diagram (b).

A method of producing an audio-frequency output in the carrier is to fix a buzzer in front of the microphone and operate the transmitter in the regular way, keying being accomplished by inserting a key in series with the buzzer.

9.3. Transport Aircraft Transmitter. WESTERN ELECTRIC RADIO TRANSMITTER NO. 27A. *a. General Description.*—This transmitter, a schematic diagram of which is shown in Fig. 9-7, has been designed for use in transport airplanes equipped with either a 12- or 24-volt direct-current power supply; it may be used for telephony, *MCW* telegraphy, *CW* telegraphy, or facsimile transmission. It delivers 125 watts of carrier power to suitable airplane antennas in the 2- to 10-megacycle range and will operate at reduced power up to 15 megacycles. As many as 10 pretuned crystal-controlled frequencies in the specified range may be set up on a motor-driven turret, any one of which may be electrically selected by a 10-position switch on the transmitter or a similar switch installed at a remote point. A mechanical coupling geared to the turret is provided for simultaneously changing the tuning of a radio receiver such as a Western Electric 29 type.

Power for vacuum-tube filaments and relays is obtained directly from the battery, whereas a 500-volt supply is obtained from a small dynamotor mounted in the transmitter, and a 1,050-volt plate supply is provided by an external power unit. A plug on the 500-volt dynamotor makes the necessary circuit changes for 12- or 24-volt operation, thus making it possible to convert the transmitter quickly for either power supply by inserting the correct dynamotor. The 500-volt dynamotor is also used as a motor to drive the turret and to provide forced ventilation by means of a fan mounted on one end of the shaft. Air is drawn into the set through a spun-glass filter and is exhausted through louvres at the front and rear.

The radio-frequency circuits comprise a quartz-plate controlled oscillator followed by two stages of radio-frequency amplification. The oscillator plate circuit is tuned to the second harmonic of the quartz-plate frequency, while the first amplifier stage operates as a straight amplifier in the 2- to 10-megacycle range and as a doubler in the 10- to 15-megacycle range. The quartz plate and tuning elements for one carrier frequency are contained in a single removable 101-type tuning unit which is permanently adjusted at the time of installation for a particular frequency and is independent of any other tuning unit. The contact pins of the tuning

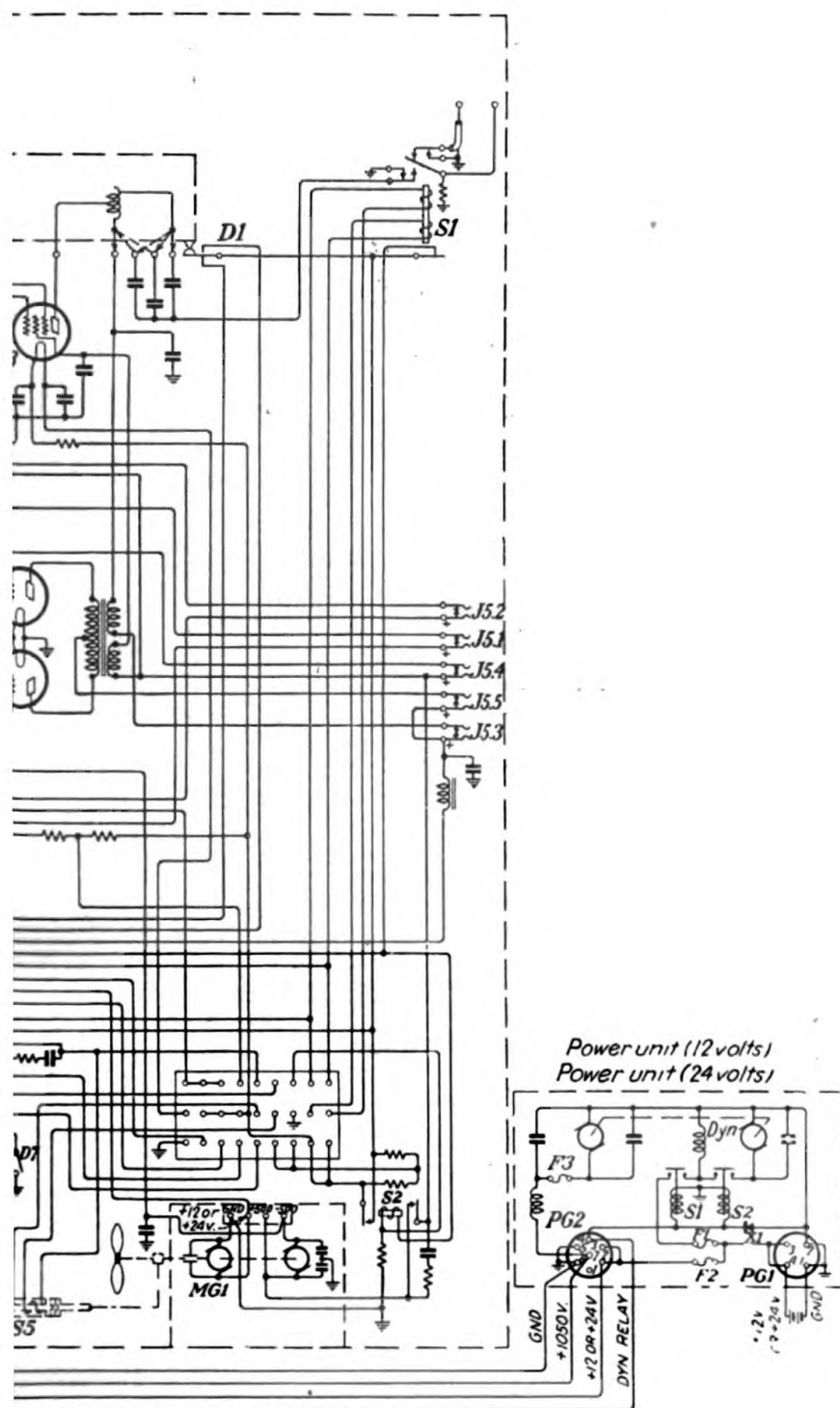
nit in the operating position engage clips on a fixed contact plate which complete all the radio-frequency circuits. Two tuning units, the 101A and 101B, are available for use with the 27A radio transmitter and are identical except for their output coils. The 101A tuning unit has an output coil of large inductance and is generally used for frequencies below 6.5 megacycles, whereas the 101B tuning unit is used above 6.5 megacycles, the division point depending on the airplane antenna used.

Audio-frequency power to modulate the final radio-frequency stage is furnished by a three-stage audio amplifier, the final stage of which operates as a class B power amplifier. Provisions are made for operation from either a dynamic or carbon microphone, and with either type substantially complete modulation can be readily obtained.

The control circuits, shown by the simplified schematic diagram in Fig. 9-8, are arranged to provide either local or remote control of the transmitter and operate as follows: The power-control switch marked ON-OFF operates the starting relay which closes the filament and relay circuits and starts the 500-volt dynamotor. When the emission switch is in the PHONE position, the carrier is controlled by the microphone push-button switch. The control contact on the push-button switch is connected into bank 3 of the emission switch and operates the antenna relay which, in addition to transferring the antenna from the receiver to the transmitter output, applies operating voltage to the starting relays in the external power unit and to the power-control relay. The power-control relay closes the output circuit of the 500-volt dynamotor and short-circuits a series filament resistor bringing the filaments to full operating voltage. In the telegraph positions, control of transmission is provided by a switch marked CODE SEND—CODE RECEIVE which takes over the function of the control contact of the microphone push button switch. In the mcw position when transmitting, the carrier is on continuously and tone modulation is provided by a feed-back circuit on the second audio stage. This feed-back circuit is operated by the audio keying relay which is connected through bank 7 of the emission switch to the telegraph key. In the cw position, the carrier is keyed by keying the bias on all the radio-frequency tubes including the oscillator. This is accomplished by connecting one side of the bias potentiometer through bank 5 of the emission switch to the telegraph key, so that when the key is up full bias voltage is applied to the grids of the oscillator and amplifier tubes, biasing them to cutoff, and when the key is down (grounded) normal operating bias is restored. Sidetone is provided by keying the same feed-back circuit as in the mcw position. Modulation of the carrier is prevented, however, by a relay, controlled by bank 6 of the emission switch, which operates to remove the excitation from the grids of the audio power tubes. In the fac position, the carrier is keyed in the same manner as in the cw position except that high-speed keying is provided by letting the oscillator operate continuously and keying only the bias on the radio-frequency amplifier tubes.

All transmitter controls are transferred to the remote-control unit when the emission and selector switches on the front of the transmitter are placed in the REM position.

Frequency selection is accomplished by control of the rotation of the turret, thus bringing different tuning units into operating position. This change from one frequency to another requires 1 to 10 sec., depending on the location of the tuning units on the turret. The selection circuits are shown in Fig. 9-9 and operate as follows: A selection commutator on the turret shaft and a 10-position selector switch are so connected that, when the turret reaches the same position as the switch, a control



dio transmitter.

relay circuit will be completed to ground, causing the relay to operate and disengage the clutch. When the selector switch is placed in a new position, the control relay circuit will be opened. This releases the relay, which in turn applies operating voltage to the clutch. The clutch will then engage, and the dynamotor will drive the turret

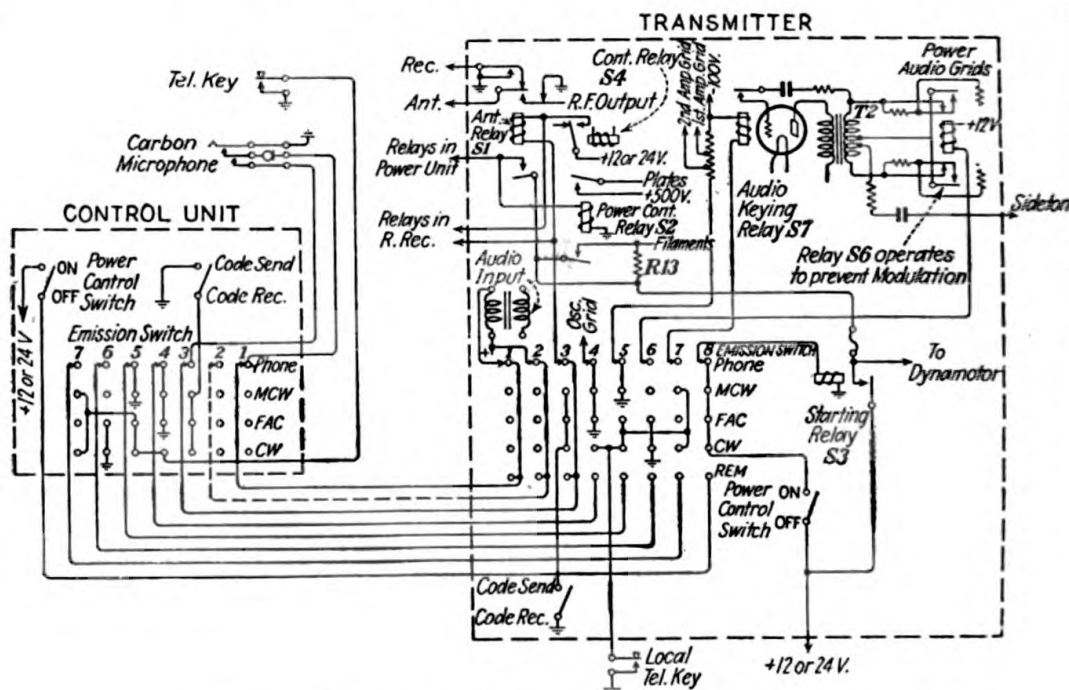


FIG. 9-8.—Control circuits of W.E. 27A radio transmitter.

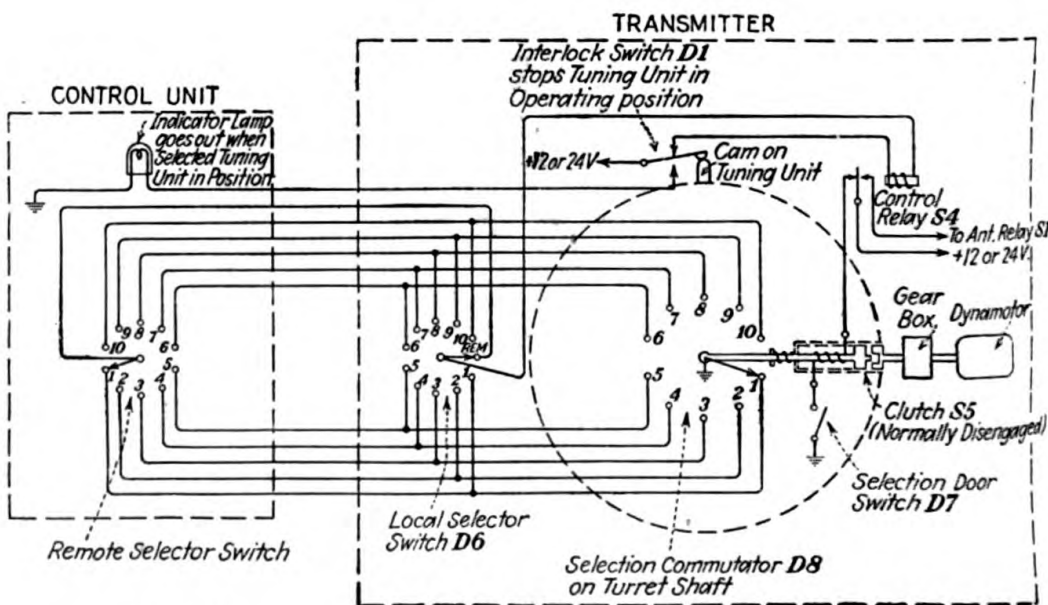


FIG. 9-9.—Frequency-selection circuits W.E. 27A radio transmitter.

until the position on the commutator corresponding to the new selected position is reached. The actual stopping of the turret, however, with the tuning unit in the operating position, is accomplished by the interlock switch. The interlock switch, when actuated by a cam on the tuning unit, applies the operating voltage to the control

relay to disengage the clutch. The selector switch in the control unit takes over the selection control when the selector switch on the transmitter is placed in the REM position. The indicator lamp in the control unit is operated by the normally closed contacts of the interlock switch so that when the selected tuning unit is reached the lamp will go out.

A power unit has been designed specifically for furnishing the high-voltage plate supply to the type 27 radio transmitter; it contains a high-voltage dynamotor which will deliver 0.4 amp. at 1050 volts direct current, fuses for the equipment, and associated filter and control circuits.

The unit may be mounted in a radio rack or in a confined space by locating the plugs and fuse compartment on the front of the unit and by employing mounting details which may be operated from the front end. Spare fuses are conveniently mounted on the rear of the fuse door and may be readily inserted without the aid of any tools.

The remote-control unit, Fig. 9-9, consists of a small photo-etched panel on which are mounted a selector switch, emission switch, power control switch, code send-receive switch, and a selection indicator lamp. Inasmuch as the desired controls usually vary with each application, the unit is supplied unwired so that it may be readily adapted to any combination of control circuits.

b. Operation.—The entire operation of the 27A radio transmitter and associated equipment has been simplified as much as possible by reducing to a minimum the number of controls. Inasmuch as the radio-transmitting equipment operates only for the duration of a radio "contact," advantage has been taken in the design of the equipment of an intermittent-duty cycle of 5 min. on and 15 min. off.

For operation from the control unit, place the transmitter emission and selector switches in the REM position, making inoperative all controls on the front of the transmitter, Fig. 9-10. When a radio "contact" is to be made, place the ON-OFF switch of the control unit in the ON position. This operation lights the filaments, starts a small dynamotor in the transmitter and, if the turret is not in the same position as the selector switch, will rotate the turret, as indicated by the blinking of the indicator lamp, until it reaches the position corresponding to that of the selector switch. The turret will then stop, and the indicator lamp will go out.

Whenever a new transmitting frequency is desired, it is merely necessary to place the selector switch in the position corresponding to the desired frequency. If telephone transmission is desired, place the emission switch in the PHONE position and operate the PRESS-TO-TALK microphone button. This operation connects the transmitter output to the antenna and applies operating plate voltage to the transmitter.

When transmission is desired on MCW, FACSIMILE, or CW, the switch marked CODE SEND and CODE RECEIVE performs the function of the microphone push button, the CODE SEND position being used for transmission and the CODE RECEIVE position for reception. The MCW position provides modulated continuous-wave telegraphy by keying the tone modulation. In the FAC position, high-speed keying, in the order of 200 words

per minute, of the continuous wave carrier is provided by keying only the bias of the amplifier stages, leaving the oscillator operating continuously. This position should be used for machine telegraphy or facsimile transmission.

The cw position should be used for hand-keyed continuous-wave telegraphy; it provides complete suppression of all the radio-frequency stages by keying the oscillator along with the amplifier stages. The keying speed is limited in this position to about 30 words per minute by

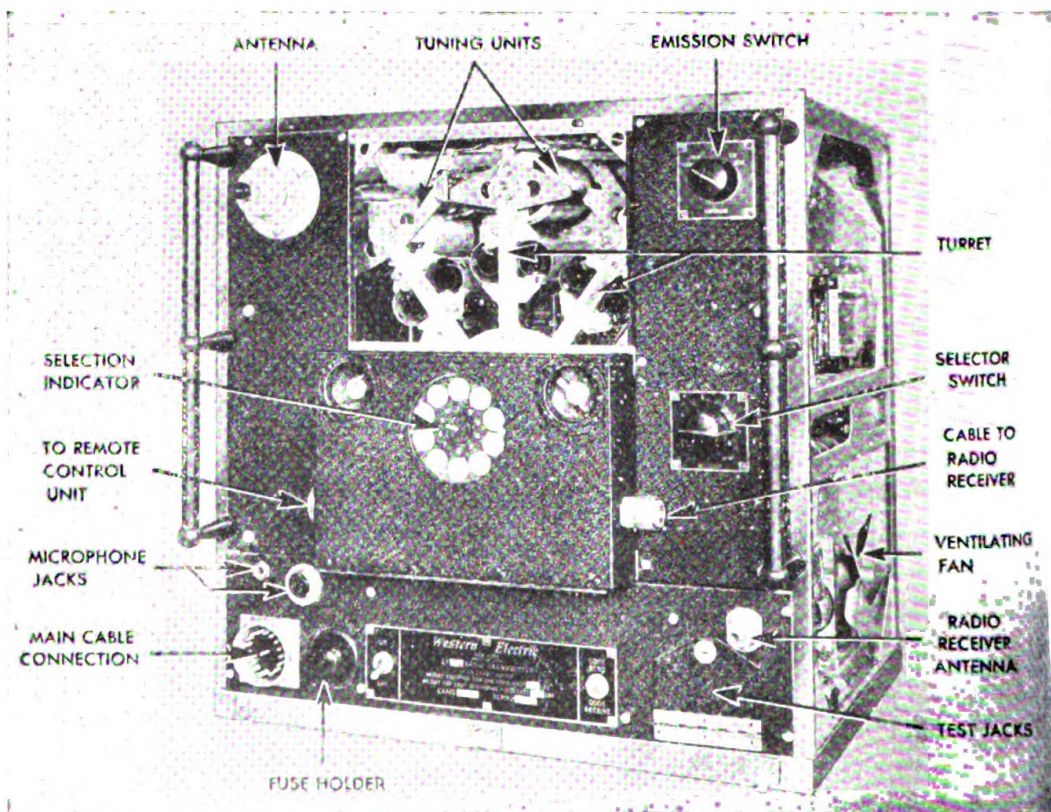


FIG. 9-10.—Western Electric aviation multi-frequency radiotelephone transmitter.

starting time of the quartz plate. At the completion of the radio "contact" place the OFF-ON switch in the OFF position.

The same procedure should be followed when operating locally by means of the controls on the front of the transmitter. The dial on the front of the transmitter will indicate in this case when the selected turret position is reached.

c. Routine Maintenance. MONTHLY SERVICE. 1. *Vacuum tubes.*—Vacuum tubes have a limited life, and unless their ultimate failure is anticipated interruption of service may result. The best safeguard is to keep a record of the date of installation and service hours of each tube. In addition, check the vacuum-tube currents at the jacks on the front of the transmitter at least once a month. Symptoms of faulty performance as indicated by these meter readings is given below.

Tube	Aging Effects Noticeable
Oscillator—W.E. 307A	Decreased 2d RF grid current
1st Amplifier—W.E. 307A	Decreased 2d RF grid current
2d Amplifier—W.E. 322A, RCA 803	Decreased 2d RF plate current with normal grid excitation
1st Audio—RCA 1E5G	Reduction of audio gain resulting in a smaller increase in 3d AF plate current with modulation
2d Audio—W.E. 300A	Decreased 1st and 2d AF plate current and reduction in audio gain as above
Power audio—2 RCA 830B	Smaller increase in 3d AF plate current with modulation

2. *Spun-glass filter*.—The ventilating inlet on the side of the transmitter is provided with a spun-glass filter which will become filled with dust. Operation of the transmitter with a dirty filter will reduce the ventilation and increase the operating temperature. The filter unit should be removed and cleaned by immersing the filter in a solution of soap and warm water and rinsing in clean warm water. New filter units should be ordered when needed.

FOUR-MONTH SERVICE. 1. *Dynamotors*.—Remove the end bells of the dynamotor. If the dynamotor has been in use approximately 1,000 hr., the bearings should be lubricated as follows: Remove the bearing grease plugs, and apply enough New York-New Jersey Lubricant Co. F-927 Grease to cover the bearings. Do not pack bearings or allow dirt to enter them. Keep the grease off the commutators. The commutators should be cleaned with a soft cloth moistened with gasoline. If the commutators are pitted, they should be carefully sanded with No. 00 sandpaper and polished with No. 0000 sandpaper. Blow out any accumulation of brush or commutator dust with clean air. Worn brushes should be replaced by new brushes of the same type.

2. *Lubrication of moving parts in transmitter*.—Apply a small amount of lubricant to the teeth of the large turret gear. F-926 Grease, which may be obtained from New York-New Jersey Lubricant Co., New York, N. Y., is most satisfactory.

Check the contact pins of the tuning units and the back contact springs. A thin film of petrolatum should be placed on the contact pins of one of the tuning units and then rotated through the contact pins several times. This will reduce wear of the contact springs and pins.

3. *Antenna relay*.—Apply one drop of Finoil or other light machine oil to the small roller in the armature of the antenna relay. Do not lubricate the solenoid plunger.

YEARLY SERVICE. 1. *General inspection*.—The equipment should be cleaned of any dust that has accumulated by blowing it out with dry compressed air. The insulating parts should be cleaned with a cloth moistened in chemically pure carbon tetrachloride. All screws, nuts, and electrical contacts should be thoroughly inspected.

2. *Gear box.*—Remove the clutch gear-box cover. If the lubricant is not up to the center line of the worm gear, add a sufficient quantity of F-926 grease, previously specified for the large turret gear, to bring it to this level.

3. *Contact pins.*—Although the pins and contact clips will necessarily show wear because of the contact pressure required for good electrical connections, they will give satisfactory service for many thousands of operations. Contact pins and clips which are worn excessively should be replaced.

4. *Relays.*—Starting relays S_3 of the transmitter and S_1 and S_2 of the power unit are completely enclosed relays requiring no adjustment or maintenance. The contacts of the other relays should be cleaned with carbon tetrachloride applied with the flat side of a toothpick or with a Western Electric 265B burnishing tool. Oil and abrasive cloth or paper should never be used.

The adjustment of the antenna relay S_1 should be checked as follows: Examine the large contacts to see that they are open (0.020 in.) when the relay is in the unoperated position. This gap may be adjusted to the correct spacing by loosening the screw supporting the roller-arm assembly. The contact pressure between these two contacts in the operated position should be about 100 to 150 grams. Observe that the transmitter output is grounded before the antenna is connected to the receiver as the relay moves from the operated to the unoperated position. The contact pressure between the receiver-antenna contacts should be approximately 35 grams. The two lower contacts (receiver grounding contact and power-control contact) should be adjusted by means of the screw on the back plate of the relay to provide a $\frac{1}{8}$ -in. air gap when in the unoperated position. When the relay operates, the contact pressure of both contacts should be 35 to 50 grams. This contact pressure is controlled by the position of the two legs of the small yoke on this lower contact assembly. An increase of pressure can be obtained by bending them slightly upward, whereas bending them down will decrease the pressure. The armature retractile spring should be adjusted with sufficient tension so that the armature reliably returns to the receive position when released. The relay should operate satisfactorily on 9 volts when the coil terminals are connected in parallel for a 12-volt system and on 18 volts when connected in series for a 24-volt system.

d. *Location of Trouble.*—A test bench will be invaluable in the event that trouble occurs in the equipment. In case it is necessary to trace any wiring, reference should be made to the wire colors shown on the wiring diagram. A volt ohmmeter should be used for such checking. Methods of locating specific troubles are discussed in the following paragraphs.

NO RADIO-FREQUENCY OUTPUT.—*a.* See that the filaments are lighted and that the 500- and 1,050-volt dynamotors are running. If not, check battery voltage, fuses in the power unit and transmitter, and the transmitter-starting relay S_2 .

b. If the antenna relay S_1 is not operated, check to see that voltage is present at the coil terminals of the antenna relay and that the control circuit is grounded by the microphone push-button switch. If the antenna relay operates, check to see that it closes the power control relay S_2 .

c. See if all the contact pins of the tuning unit are properly engaged in their spring clips.

d. Measure the currents at the test jacks on the front of the transmitter with a KS-7313 milliammeter or its equivalent. The radio-frequency circuits should be checked stage by stage, beginning with the oscillator. No oscillator grid current indicates that the quartz plate is not oscillating, which in turn may be due to a defective quartz plate or oscillator tube, no plate voltage, or an open circuit.

If the oscillator is operating properly, measure the second radio-frequency grid current which will indicate the operation of the first amplifier tube. The second amplifier tube can be checked by measuring the second radio-frequency plate current.

LOW RADIO-FREQUENCY OUTPUT.—With full battery voltage, low radio-frequency output may be due to a defective quartz plate, radio-frequency tube, dynamotor, or a detuned radio-frequency circuit.

NORMAL OUTPUT BUT NO MODULATION.—This indicates defective apparatus or an open circuit in the audio amplifier.

a. Try another microphone.

b. Place the test meter in the third audio-frequency plate-current jack, and make a loud sustained noise in the microphone. The current should rise from approximately 30 to 200 ma. The failure of this current to rise indicates defective power audio tubes or trouble in the audio driver stages.

c. Place the test meter in the first and second audio-frequency plate-current jack. If this current is very low, try a new second audio tube, whereas if the current is normal replace the first audio tube. If the trouble has not been located by a change of tubes, it will be necessary to remove the small audio panel and check wiring and apparatus.

d. If the transmitter operates satisfactorily on PHONE but does not modulate on MCW, check the small audio keying relay S_7 to see that it closes the audio feed-back circuit when the telegraph key is pressed.

FAILURE OF FREQUENCY SELECTION.—Try selecting a different frequency. If the turret does not turn, check the clutch S_3 to see that operating voltage is applied by the control relay S_4 . If the turret rotates but does not stop in position, see if the control relay operates when the turret passes through the selected position. Failure of the control relay to operate may be due to faulty operation of the interlock switch D_1 or the selection commutator D_2 .

TESTING WITH ARTIFICIAL ANTENNA.—It will be found advantageous to check the overall performance of the complete transmitting equipment by first operating the transmitter into an artificial antenna. Such an antenna should consist of a 0- to 5-amp. radio-frequency ammeter in series with a 15- to 25-ohm non-inductive resistor capable of dissipating 125 watts, connected between the antenna terminal and ground. The plate and antenna rollers of the output coil should be placed on the front (HIGH) end of the coil, care being taken to ascertain that the roller connections are on a turn and not between turns.

e. Installation.—The location of the radio equipment will probably be determined during manufacture of the airplane, and the following factors should be considered as early as possible in the course of the airplane construction. These factors apply, of course, to installation of the radio equipment in an existing airplane.

1. The KS-10044 Power Unit should be located near the plane's battery supply so that the weight and size of the power cables will be a minimum.

2. The 27A Radio Transmitter should be located so that a short antenna lead-in connection and a good radio-frequency ground connection to the plane's structure can be obtained. This is especially true if frequencies above 10,000 kilocycles are to be employed. The transmitter should also be located as near the KS-10044 power unit as possible in order that the weight and size of the low-voltage power connections will be a minimum.

3. The Remote-Control Unit must be located in a position that is visible and within reach of the pilot or radio operator. If the pilot is to control the radio functions, it is recommended that the control unit be located on the instrument panel of the airplane.

The ideal location for the transmitter, power unit, and main junction box is in a shockproofed rack at the front of the ship near the plane's battery supply. The transmitter should be located in the upper portion of the rack near the antenna leadin and the power unit in a small compartment at the bottom of the rack near the plane's battery supply. With this arrangement, all the controls, cable connectors, and fuses of the transmitter and power unit will be completely accessible from the front of the rack and the size and weight of the interconnecting cables will be small.

GROUNDING.—If the transmitter is to be mounted in a shockproof radio rack, a short ground connection of heavy copper braid should be made from the rack to the metal structure of the airplane. The connection between the transmitter and radio rack is obtained by cleaning the channels of the rack on which the transmitter mounts and positively grounding the front and rear mounting details to the rack. The same type of ground connection should be provided for the transmitter when it is mounted on a separate shockproofed mounting plate.

f. Antennas.—The most convenient antenna to use with the equipment is a fixed antenna. Satisfactory results with this type of antenna over the frequency range will be obtained provided the antenna wire is well spaced from the metal part of the ship and a suitable length employed. If the transmitter is to be located in the front of the ship, the fixed antenna recommended is a single wire run from the top of the fin, forward (parallel to the slip stream) to a stub mast at the front of the fuselage, with the lead-in insulator at the forward end (see Fig. 9-17a). This

antenna will probably be satisfactory down to 2,000 kilocycles provided the airplane is large enough to provide an antenna length of 50 ft. or more. The stub mast should be at least 2 or 3 ft. high to provide ample clearance between the wire and ship. If the transmitter is located in the rear of the ship, a wire can be run from each wing tip to the top of the vertical fin, with the leadin from the apex of this V.

An untuned trailing-wire antenna (Fig. 9-17*e*) is not recommended unless the desired frequencies are all in the low end of the frequency range. A trailing-wire about 50 ft. long should be used for frequencies below 4,000 kilocycles and about 25 ft. for frequencies above 4,000 kilocycles. It should be fastened to the apex of the tail cone by means of a shear pin in an insulating bushing and connected to the transmitter by means of an unshielded leadin spaced on insulators from the ship structure. This leadin should be as short as possible and routed as far as possible from all metal parts.

When an adjustable trailing-wire antenna is to be used, the control for adjusting the length of wire must be conveniently located for the person operating the transmitting equipment. The same type of leadin should be used as described for the untuned trailing-wire antenna.

g. Microphones.—Either the carbon or the dynamic types of microphones may be used. This is possible because the transmitter amplifier permits full modulation with signal inputs down to -42 VU with a zero-level calibration of 0.001 watt. This is equivalent to -50 db with a zero-level calibration of 0.006 watt.

A jack is provided to accommodate the standard Western Electric 109 microphone plug or the newer type positive-locking plug designed primarily for dynamic microphones.

h. Associated Receiver.—When radiotelephone reception is desired, one of a number of aviation radio receivers may be used. The Western Electric 29A receiver is particularly recommended when the 27A transmitter is used. When these two units are used together, a mechanical coupling geared to the turret of the transmitter adjusts the receiver simultaneously with the transmitter.

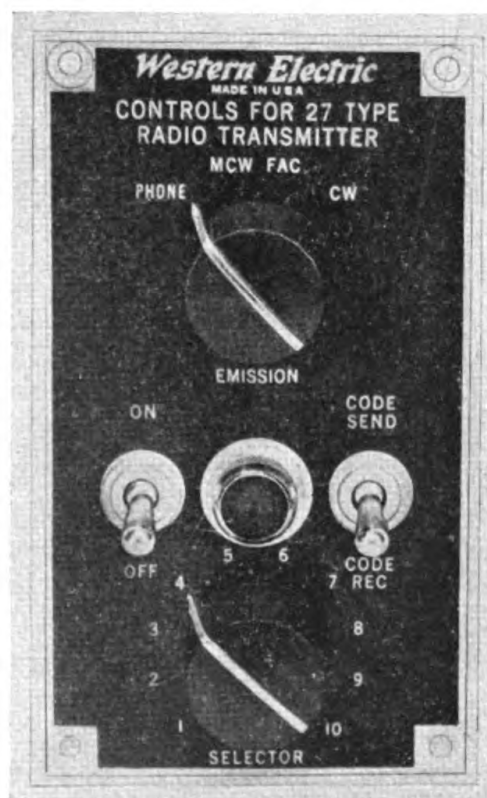


FIG. 9-11.—Remote control unit.

9.4. Maritime Aircraft Radiotelegraph Transmitter. *a. Development.*

The Pan American Airways which conducts much of its flying over tropical waters has found radio telephony unsatisfactory and uses radio telegraphy exclusively for all its radio-communication work. Although an operator must be carried, there are advantages to this method in that not so much shielding of the ignition system is required, accuracy and

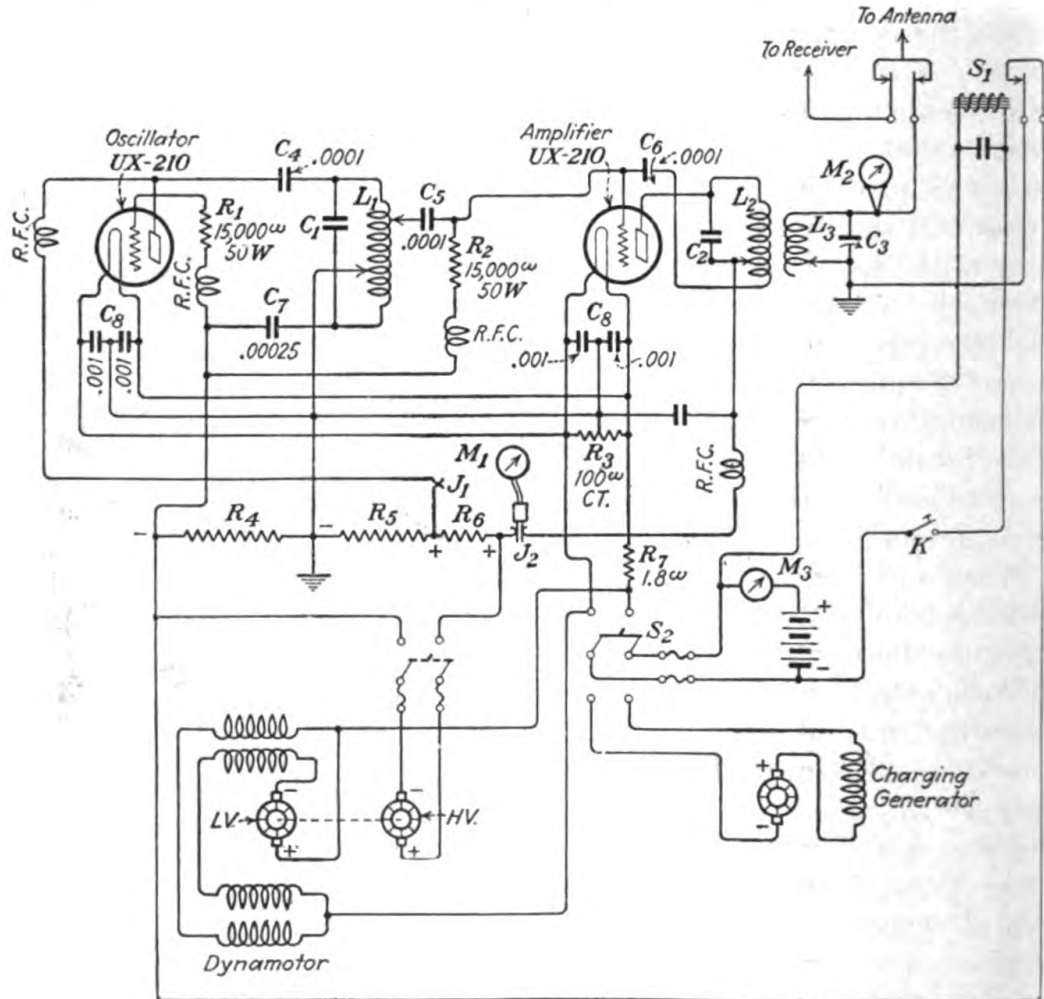


FIG. 9-12.—Typical radiotelegraph transmitter for aircraft.

speed of message handling are increased, and ground stations do not need to be so close together. Communication is secured up to 1,800 miles.

To meet international regulations, aircraft radio equipments for use in overwater flights must be capable of working on 500 kilocycles as well as on the regular international air-service calling frequency of 333 kilocycles. In addition to these required intermediate frequencies, it was found that increased efficiency in the face of terrific tropical static could be secured on the high frequencies. Accordingly the transmitters used in this service are also designed to work on several high-frequency channels, notably 3,090 and 5,550 kilocycles.

b. The Transmitter.—A circuit diagram of a radiotelegraph transmitter, very similar to a type used on aircraft of the Pan American Airways, is shown in Fig. 9-12. Because of the constant evolution and improvements in construction, this circuit cannot be considered as actual in every detail. It is, however, representative of the transmitter use.

The transmitter is rated at 12 watts and utilizes two -10-type tubes in a master-oscillator power-amplifier circuit. The oscillator is of the split inductance or Hartley type. A distinctive feature of this transmitter is that plug-in inductance and capacity units are used for each frequency employed. An adjustable tank condenser is a part of each plug-in unit, there being two units for each frequency, one unit for the oscillator and one for the amplifier, as shown in the diagram. The capacity required is achieved by proper adjustment of the unit when the set is tuned. After this initial adjustment, it is unnecessary for the operator to tune the tank circuit when shifting frequency. The only tuning adjustment is the antenna oscillatory circuit (L_3C_3) which consists of a tapped inductance and a variable condenser. Thus to shift from one frequency to another the operator simply inserts the proper plug-in units and resonates the antenna for proper radiation.

On the Pan American aircraft transmitters, used in the tropics, short- and medium-distance traffic is handled on a day frequency of 5,692.5 kilocycles and a night frequency of 3,082.5 kilocycles. In addition to these frequencies, long-haul day traffic is handled on 8,220 kilocycles for distances of 500 or 600 miles, depending on conditions. Frequencies of 500 and 333 kilocycles are also provided as required by international law for aircraft flying over water as stated before.

Keying the radiotelegraph is accomplished by keying the grids of both the oscillator and the amplifier. It will be noted that when the key is up a blocking bias is developed across R_4 which stops operation of both tubes. When the key is down (closed), the grids are connected to the filament center-tap through their respective grid leaks and radio-frequency chokes as shown in the circuit diagram.

Plate current for both tubes can be read by the milliammeter M_1 which is fitted with a plug for insertion into either the oscillator or amplifier plate-circuit jacks J_1, J_2 . Antenna current is read from the thermocouple meter M_2 . A zero-center ammeter M_3 is inserted in the positive storage-battery lead which reads "charge" or "discharge" current.

The relay S_1 provides break-in operation. When the hand key is pressed, all relay armatures are drawn toward the relay core. This action removes the blocking bias from the grids of both tubes by connecting the remote end of R_4 to the ground thus short-circuiting it; the inductance L_3 is connected to the antenna, and the receiver is disconnected from the antenna. When the key is released, the relay armatures

spring back disconnecting the transmitter from the antenna while connecting the receiver to it, and the blocking bias taken from across R_4 is applied to the grids of the tubes.

The primary source of power for the transmitter is a 12-volt storage battery which operates the tube filaments and the relay S_1 and drives a dynamotor which delivers high-voltage plate potential. The rating of the dynamotor is 400/12 volts, 70 ma./8 amp. No filtering is required.

The storage battery is recharged by a small generator rated at 6,500 r.p.m., 14 volts, 5 amp. This machine is driven by either the engine of the plane or a wind drive.

The voltage-divider resistance is made up of units R_4 , R_5 , and R_6 . Unit R_4 provides blocking bias for both tubes for keying purposes, R_5 is a bleeder resistance, and R_6 drops the voltage to the proper value for the oscillator.

The transmitter can be started and stopped by the main power switch S_2 which also serves to put the battery on charge. The high-potential plate supply is controlled by a double-pole single-throw knife switch, and all lines are properly fused.

II. RECEIVERS

The requirements of the aviation service call for important departures from conventional receiver design. Many features not required in other types of receivers are highly desirable in receivers designed for installation aboard aircraft.

The aircraft receiver must combine high sensitivity with a minimum number of tubes, and it must of necessity operate on a small power supply. Both of these requirements are met by the use of multi-grid and single-grid high- μ tubes. The aircraft receiver must be easy to adjust and be positive in its adjustment with a minimum number of controls. It may or may not be designed for operation on the low- and high-frequency aviation-service bands.

The aircraft receiver must be light in weight, and it is desirable that AVC be provided in addition to manual control. Finally, the aircraft receiver must be as immune as possible from the effects of weather, especially in so far as it affects its frequency calibration. The aircraft receiver must also be thoroughly shielded to reduce induced interference from the ignition system to a minimum.

9.5. Transport Aircraft Communications Receiver: WESTERN ELECTRIC RADIO RECEIVER No. 29A. *a. General Description.*—This receiver, a photograph of which is shown in Fig. 9-13A and a schematic diagram in Fig. 9-13B, is designed for air-transport communication service. It is a superheterodyne receiver operating over the frequency range of 2 to 15 megacycles with an intermediate frequency of 385 kilocycles. It includes one radio-frequency amplifier tube, a first detector tube, two

intermediate-frequency amplifier tubes, a second detector and audio amplifier tube, and two audio-frequency output tubes. There are also an input limiting tube, a crystal oscillator tube, automatic gain-control tube, and heterodyne oscillator tube for *C-W* telegraph reception.

The connection between the antenna and the radio receiver is made by means of a plug, which will accept a shielded conductor, through the jack J_1 and series trimming condenser C_1 to the tuned circuit made up of condenser C_1 in parallel with one of the coils L_1 to L_{10} . The proper coil is selected by switch D_2 which also short-circuits the unused coils. The antenna circuit normally matches an antenna of about 100 mmf. capacity, but it can be made to match antennas of lower effective capacity by switching in compensating condensers by means of the switch D_1 .

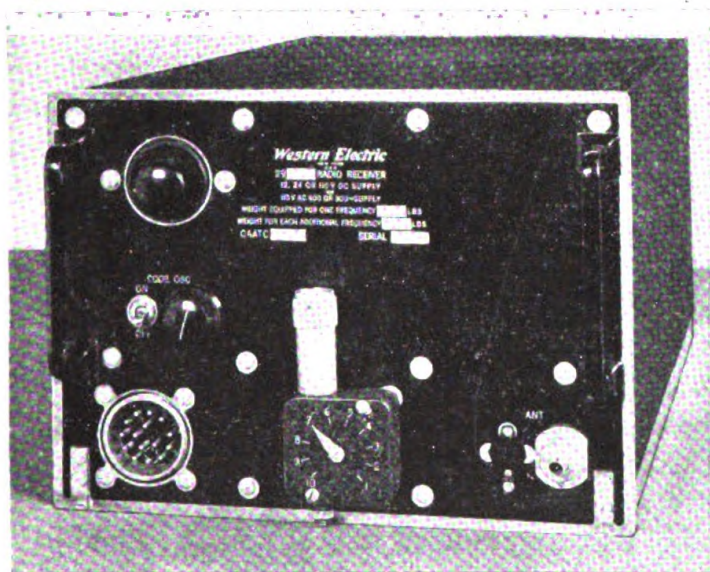


FIG. 9-13A.—Western Electric ten-channel aviation radio receiver 29A.

A static drain resistance R_1 is provided. The circuit through C_7 , the vacuum tube V_1 , and resistances R_3 and R_4 which provide bias to V_1 is a volume-limiting circuit to protect the radio receiver from excessive antenna voltages, thereby improving the AVC at great signal strengths.

Between the radio-frequency amplifier tube V_2 and the first detector tube V_3 is a band-pass filter made up of coils L_{11} to L_{20} and L_{21} to L_{30} tuned, respectively, by condensers C_9 and C_{10} . The two circuits are coupled together by means of condenser C_{11} . Switches D_3 and D_4 select the appropriate coils and short-circuit all unused coils.

The oscillator tube V_{10} is connected to the proper quartz plate in turn by means of switch D_5 . Its circuit is arranged so that heated crystals can be used, if desired, in which case the heaters are excited from an external circuit through terminal 3 of the power plug. The crystal heater circuit requires a maximum current of 4 amp., each unit requiring 0.4 amp.

Following the first detector tube V_3 are two intermediate-frequency amplifier tubes V_4 and V_5 coupled by means of band-pass filters. Following the third band-pass filter are a second detector and audio amplifier tube V_6 and an automatic gain-control tube V_7 .

AVC for this receiver is derived from a separate vacuum tube V_7 . The *AVC* is of the delayed and amplified type. The initial sensitivity of the receiver is adjusted by means of a variable resistance in the control unit connected to terminals 5 and 6, which adjusts the initial bias on the amplifier tubes in order to limit the receiver sensitivity as static conditions may require. Additional bias for *AVC* is derived from the voltage drop across resistance R_{28} caused by the space current of tube V_7 .

The detector and audio amplifier is followed by two power output tubes V_8 and V_9 having a common input circuit and individual output transformers.

V_{11} is an oscillator tube for *CW* telegraph reception with control switch and frequency adjustment on the front panel. The voltage from this oscillator is applied to the detector by a small condenser made up of terminals adjacent to condenser C_{19} in the detector circuits.

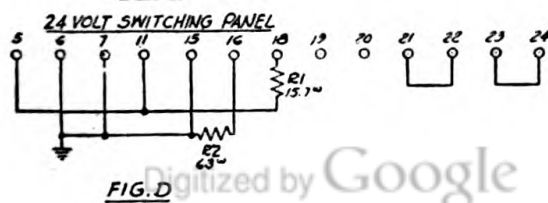
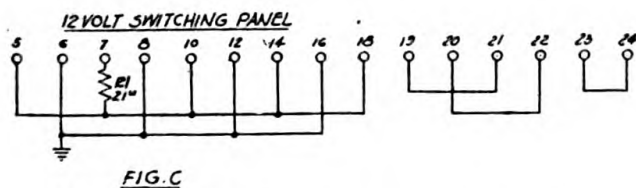
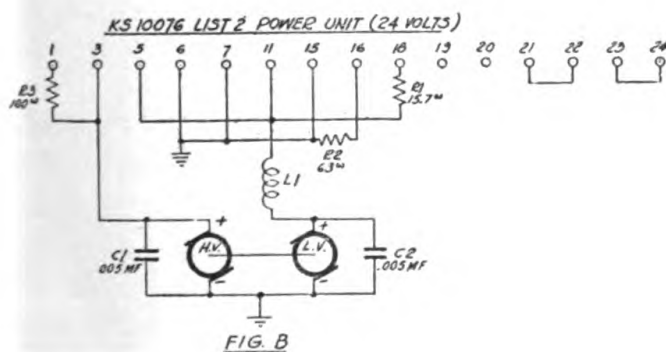
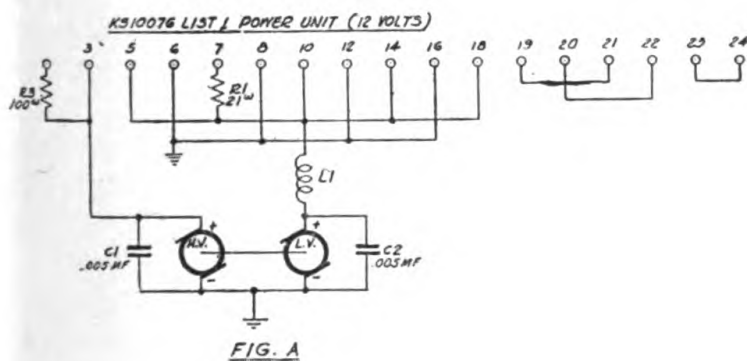
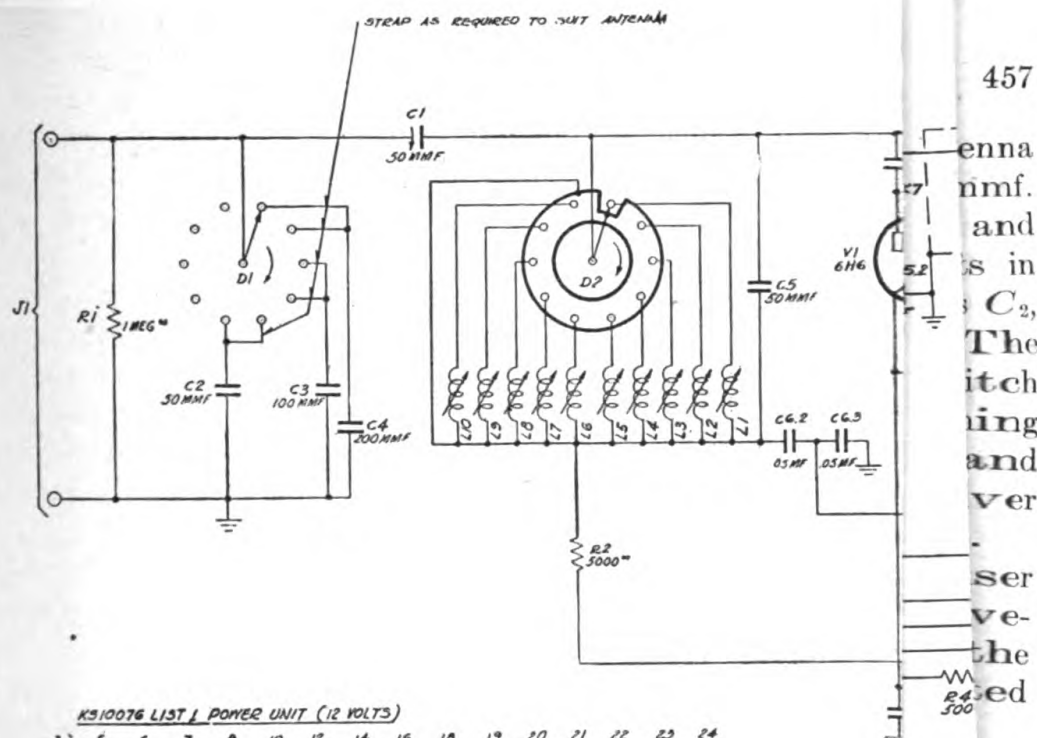
Three relays are included in the receiver. Their windings are designed for 12-volt operation and are connected in series-parallel for 24-volt operation. This switching is automatically provided by the switching panel or by the dynamotor units.

Relay S_1 disables the receiver by removing the screen voltage from the amplifier tubes. Relay S_2 closes the side-tone circuit. Relay S_3 is included to open the circuit from the beacon receiver or to perform any other desired operation when the transmitter is in use. These relays require a total of 0.36 amp. under 12-volt operation and 0.18 amp. under 24-volt operation.

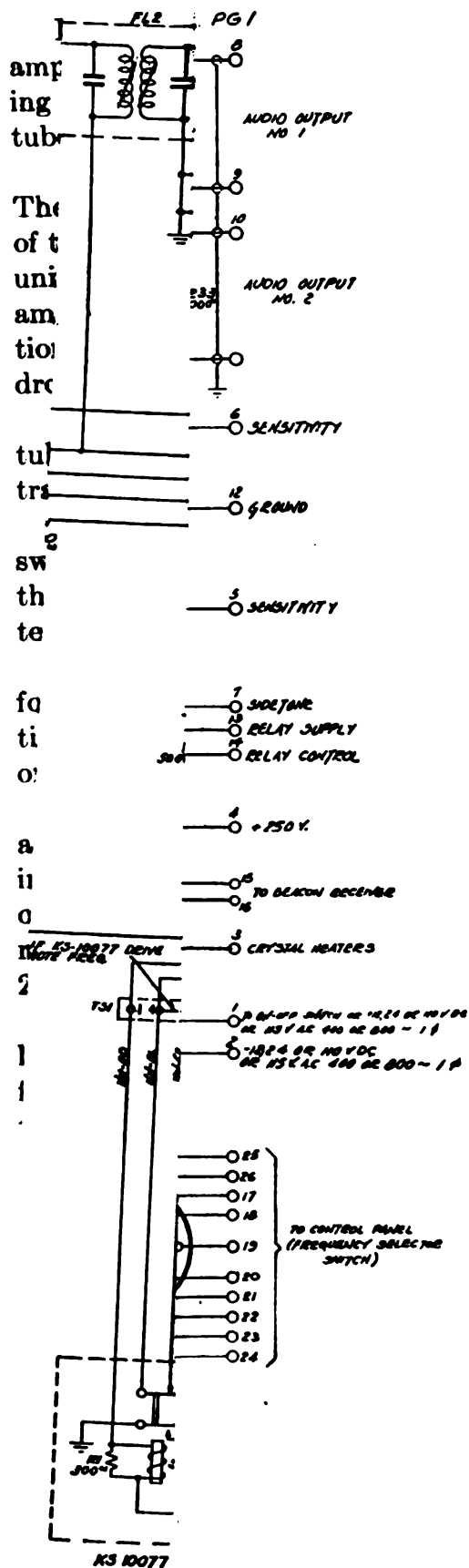
b. Operation and Maintenance.—With the receiver turned on, and a large signal at the antenna terminals from a signal generator at the proper frequency, the three 16-type tuning coils in the channel under consideration should be adjusted to resonance. Reduce the gain and generator output as needed so that *AVC* does not lessen the apparent selectivity of the coil under adjustment.

When the circuits have been adjusted to the signal generator, the receiver should be connected to an antenna (real or artificial) of the type actually in use on the airplane. The first coil should then be returned to suit the antenna. If an artificial antenna is available for use with the signal generator, the first and second operations can be combined. The artificial antenna should be as exact an equivalent of the actual antenna as possible.

NOTE.—The antenna trimming condenser should be near maximum capacity during these adjustments.



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If the tuning seems very broad, indicating a high-impedance antenna at the particular frequency involved, condensers of 50, 100, or 200 mmf. should be tested in turn between the antenna terminal and ground, and when one is found that makes the tuning reasonably sharp and results in good sensitivity, the corresponding capacity chosen from condensers C_2 , C_3 , and C_4 should be strapped to the proper terminal of switch D_1 . The same condenser may be strapped to any number of terminals of switch D_1 as required. Test for proper tuning of the radio receiver by switching to each of the frequencies for which the receiver is equipped in turn and readjust the antenna trimming condenser. An exactly tuned receiver will require no retuning of the trimming condenser for any frequency.

When the receiver is installed in the airplane, the trimming condenser provides a single line-up adjustment for all frequencies. Its effectiveness depends upon how well the circuits were originally tuned to the standard antenna and on how nearly the standard antenna is duplicated on the particular airplane.

The sensitivity control connected to terminals 5 and 6 of the radio receiver is not a volume control. Its function is to adjust the no-signal sensitivity of the receiver to a value such that normal atmospheric noise is not annoying; its setting may vary with the signal strengths to be expected from various transmitters. Volume controls to adjust the loudness of the sound at each headset should also be provided; the setting of these is adjusted to suit each pilot. The sensitivity control when fully advanced will not increase the volume from a signal.

The output level may be adjusted between the limits of approximately 100 and 500 mw. by changing the value of the output tube biasing resistor R_{41} . This will result in some decrease in the high-voltage power required.

The power units should be inspected after 1,000 hr. of operation and lubricated with New York-New Jersey Lubricant Co. No. F-927 Grease. Care should be taken that excessive lubricant does not get on the commutators. If replacement brushes are required, they may be obtained.

The electric drive is installed on the front panel of the receiver. The four wires operating the drive and the receiver disabling circuit pass through the same hole in the front panel as the drive shaft and are connected to the terminal strip TS_1 , connecting the wires to the terminals on which the same colors appear. An alignment pin on the drive shaft engages a slot in the receiver shaft to insure alignment of the detents in the drive with the switch positions in the receiver.

Operation of the electric drive is as follows: The terminal corresponding to the desired position is grounded by means of the selector switch in the cockpit. This closes the circuit through the drive relay which operates and closes the circuit through the drive motor. The relay circuit is opened when the switch arrives at the proper position, and the relay releases and the motor stops. If trouble should develop in the

electric drive or the associated control circuits, the drive may be disconnected by operating the disabling switch located on the drive unit. The desired operating frequency may then be selected by rotating the knob on the front of the unit. If electrical failure occurs with the indicating line on the knob between channel positions, rotate the worm shaft on underside of the drive to the nearest channel, and thereafter any channel may be selected manually.

The circuit (through terminals 3 and 4 of the terminal strip TS_1 in the receiver and the back contact of the drive relay) which supplies screen voltage to the first three amplifier tubes is opened during selection to disable the receiver and reduce noise. The strap normally connecting terminals 3 and 4 must be removed when the electric drive is used.

The ball bearings of the motor are lubricated with Lubriko M-6 grease at the time of manufacture and for intermittent service, inspection should only be required at yearly intervals. If lubrication is required, add only a small quantity of this grease. Excess grease may reach the commutator. If new brushes are required, they may be ordered. The worm, worm gear, and bearings on the slow-speed shaft should be lightly lubricated with any good grade of machine oil every 6 months. The worm shaft bearings require no lubrication.

The shaft of the tachometer-shaft drive unit is also provided with an indexing pin to engage the slot in the receiver shaft. The drive mounts with two screws and a clamping ring which allows the drive shaft to leave the receiver in any direction in the vertical plane. The position index is furnished with a set screw so that it can be adjusted to suit the position of the drive. The gears should be lubricated with a good grade of grease, such as Lubriko M-6, New York-New Jersey Lubricant Co. F-927 Grease or a mixture consisting of 60 per cent Texaco Star Grease No. 00, and 40 per cent Spring Eaze Oil by weight. Worm and worm-gear shaft bearings should be lubricated with any good grade light machine oil.

If *CW* reception is not used, the oscillator tube V_{11} may be omitted if a filament-compensating resistance is substituted. A mounting nut is riveted in the chassis near the socket for the compensating resistance, which should be connected across the filament terminals of the socket (terminals 2 and 7).

A Ward-Leonard $1\frac{1}{2}$ -in. Z resistor, 21 ohms ± 5 per cent, with 206 type terminals, mounted with $1\frac{7}{8}$ in. 6-32 screw, cadmium plated, and two red fiber washers $\frac{5}{32}$ in. inside diameter, $\frac{3}{8}$ in. outside diameter, $\frac{1}{32}$ in. thick may be used.

9.6. Radio Beacon and General Purpose Receiver: WESTERN ELECTRIC RADIO RECEIVER No. 25C. *a. General Description.*—The Western Electric 25C radio receiver, shown in Fig. 9-14A, is a three-band superheterodyne receiver designed for use in airplanes in which space is at a premium. The first band covers the range of frequencies from 195 to

415 kilocycles, providing facilities for the reception of weather and beacon signals from the Department of Commerce radio-range stations. The next band covers from 495 to 1,200 kilocycles, which includes the international distress frequency and the greater part of the broadcast range. A high-frequency band from 2,800 to 6,800 kilocycles permits the reception of signals from the air-transport companies' ground stations and certain commercial and amateur radio stations. Provision is made for crystal control of any two frequencies in this band, aiding in communication with commercial air-line stations. An oscillator is provided for reception of *CW* telegraphy in all bands. The receiver is supplied com-

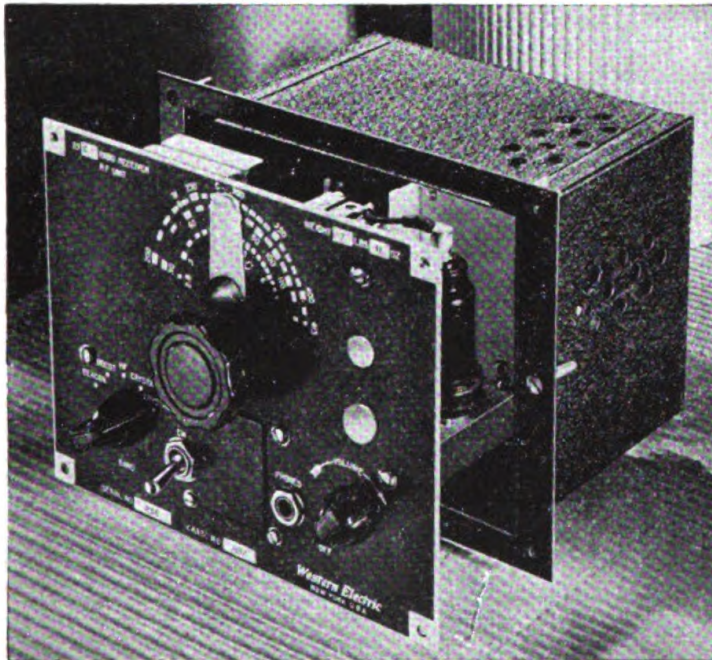


FIG. 9-14A.—Western Electric aircraft radio receiver 25C.

plete with radio-frequency unit, power unit, battery and power cables (10 ft. long and equipped with plugs), one set of vacuum tubes and fuse.

This receiver is constructed in two units, one of which, the radio-frequency unit, is designed to mount in the instrument panel of the airplane. This unit contains all controls which must be accessible to the pilot. The second, power, unit can be installed anywhere in the airplane and in any position within the limits imposed by the 10-ft. interconnecting cable and battery cable. This unit comprises the intermediate-frequency amplifier and second detector together with the *CW* oscillator, audio-frequency amplifier, and dynamotor power supply.

b. Description of Circuit.—The schematic diagram of the receiver is shown in Fig. 9-14B. There are two radio-frequency tuned circuits TU_1 and TU_2 connected in the grid and plate circuits, respectively, of the radio-frequency amplifier tube V_1 . A combined oscillator and first

detector tube is employed. The oscillator tuned circuits are contained in a tuning unit. The intermediate-frequency output of the first detector is transmitted to the power unit through the tuned output transformer T_1 and a concentric transmission line. In the power unit, the voltage is stepped up by the tuned circuit FL_1 and applied to the grid of vacuum tube V_3 . The signal is amplified by the intermediate-frequency amplifier

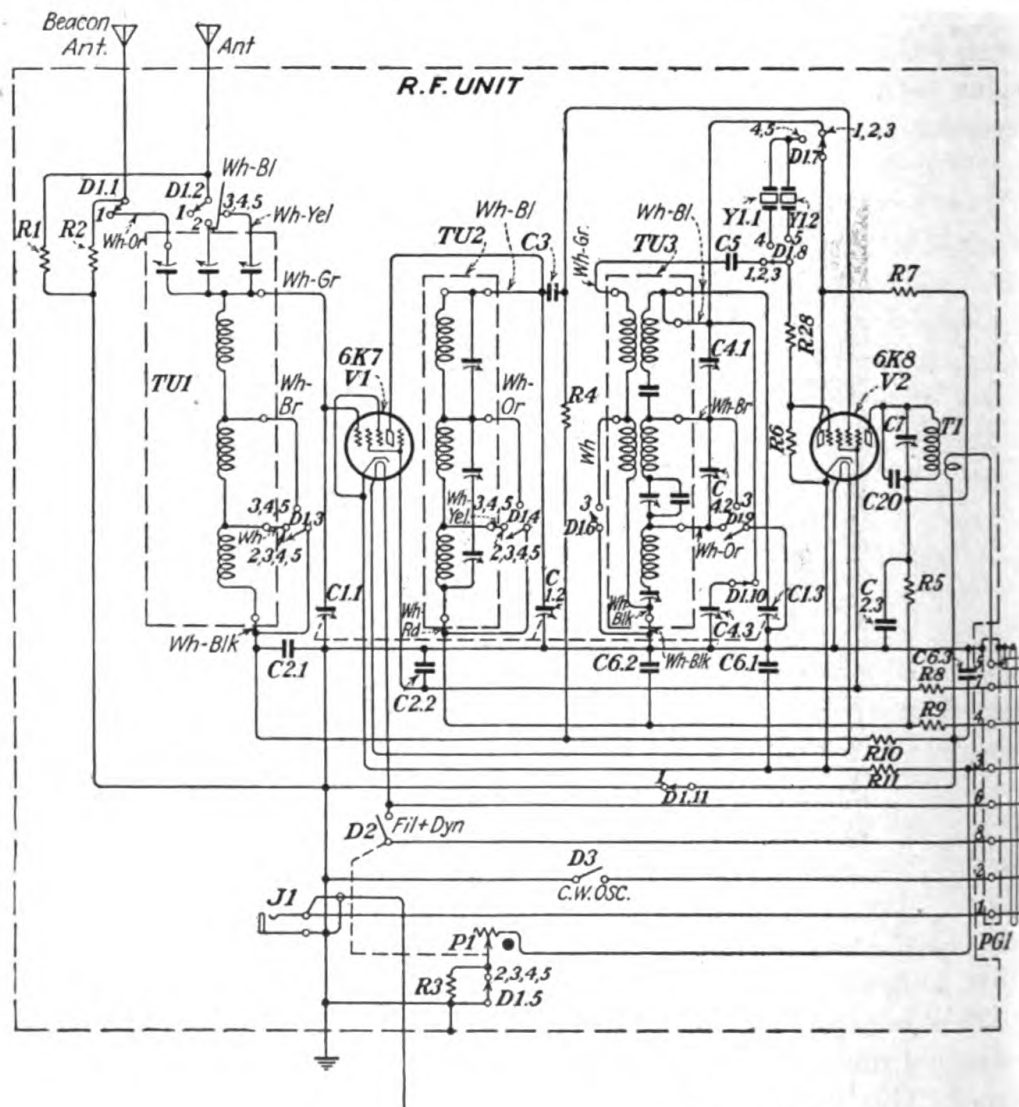


FIG. 9-14B.—Western Electric

tube V_3 and is applied to the second detector through the filter FL_2 . The detector is resistance-capacity coupled to the audio-frequency amplifier tube V_5 . V_6 is the oscillator tube for *CW* reception. This receiver employs an intermediate frequency of 455 kilocycles.

The band switch D_1 , in addition to selecting proper coils for the various frequency ranges, connects into the oscillator circuit at will either of the two crystals in the high-frequency communication band. Crystal control of reception is accomplished by switching to the proper crystal

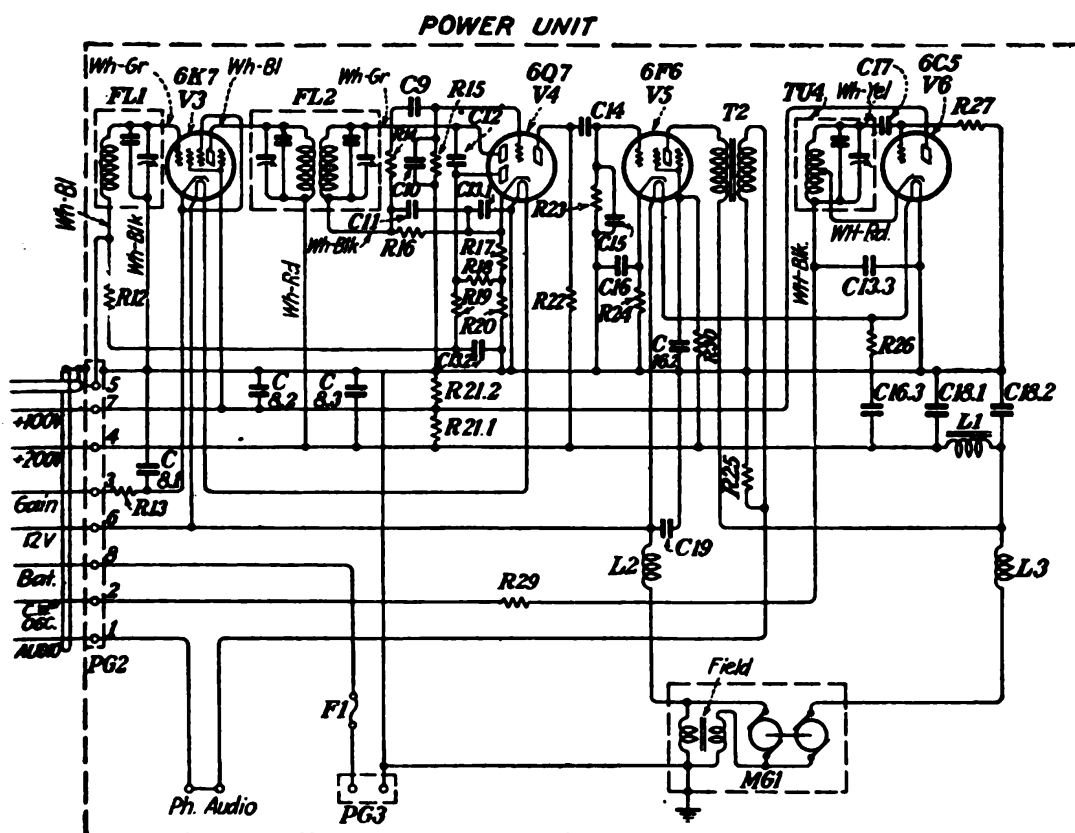
(the lower numbered crystal has the lower frequency) and tuning the receiver for maximum response.

The power switch is operated by the volume-control knob to switch the receiver off when the volume control is turned to minimum.

The AVC in the receiver is automatically disabled when the band switch D_1 is set for beacon reception.

c. Operation of Receiver. NON-CRYSTAL OPERATION.—Selection of the proper band is made by the BAND switch at the left. The desired station within the band is tuned by means of the selector knob in the middle of the panel. The volume is controlled by the knob at the right.

CRYSTAL OPERATION. A 5D quartz plate calibrated for each pair of frequencies which it is desired to receive is necessary for crystal operation of the receiver. If only one crystal-controlled frequency is required, a



25C receiver circuit.

5A quartz plate may be used. When a 5A quartz plate is used, it is connected for the lower frequency position of the band switch. Having inserted the quartz plate and having set the band switch to the proper position, the tuning indicator should be turned to indicate the frequency of the desired signal.

Since the intermediate frequency of this receiver is 455 kilocycles, the receiver will receive two frequencies for each crystal frequency, one at 455 kilocycles above the crystal frequency and the other 455 kilocycles

below the crystal frequency. Normally, the crystal is chosen to have a frequency lower than the signal.

d. Shielded Loop Antenna.—The Western Electric 25C radio receiver may be operated with a Western Electric 3A low-impedance shielded loop antenna by employing the 102A tuning unit as shown in Fig. 9-15. This combination enables the pilot or operator of an airplane to use either an open-beacon antenna or a shielded loop for beacon reception over a frequency band of 195 to 415 kilocycles and provides, in addition, a null direction finder. The use of the shielded loop provides a means of protection against rain and snow static.

The Western Electric 102A tuning unit consists of an input transformer for operation with a loop antenna and a low impedance line, a transfer switch and a trimming condenser, all assembled on an L-shaped bracket which is designed to mount on the rear of the face panel of the 25C radio receiver.

e. CW Reception.—Reception of *CW* telegraphy can be had at any frequency within the range of the receiver by operating the switch D_1 at the left of the crystal socket. If crystal control is used, the signal note can be adjusted only by means of the condenser in the top of tuning unit TU_4 in the power unit. This condenser controls the frequency of the beating oscillator which should be 454 or 456 kilocycles. Adjust the oscillator, if it requires readjustment, for maximum volume in the telephones, which will give approximately the desired frequency.

f. Maintenance.—This receiver should require little maintenance other than periodic replacement of worn-out vacuum tubes or dynamotor brushes. The electrolytic condensers may require replacement after considerable service.

If there is reason to believe that the receiver, operating with crystal control, does not have sufficient sensitivity, it may be desirable to realign the intermediate-frequency amplifier circuits. Perform this alignment on the station for which a crystal is available. Adjust C_4 , at the right rear of the radio-frequency unit, and the condensers in the intermediate-frequency transformers FL_1 and FL_2 for maximum output. If this adjustment is to be made in non-crystal operation, use a signal in the lower part of the beacon band, unless a signal generator is available, in which case it should be tuned to 455 kilocycles and connected to the grid of V_2 .

If it is desired to realign the radio-frequency circuits, the radio-frequency unit must be removed from the instrument panel and the realignment performed *with the cover in place*.

Align circuits in the following order: (1) the high-frequency band, (2) the broadcast band, and (3) the beacon band. In each band, first align the oscillator-circuit shunt trimmers (condensers at rear of chassis) so

that the signal frequency coincides with the indication of the dial at the upper frequency limit of the band in question. Then align the antenna and interstage tuned circuits by means of the condenser screws in TU_1 and TU_2 . These screws are arranged with high frequency at top, low frequency at bottom.

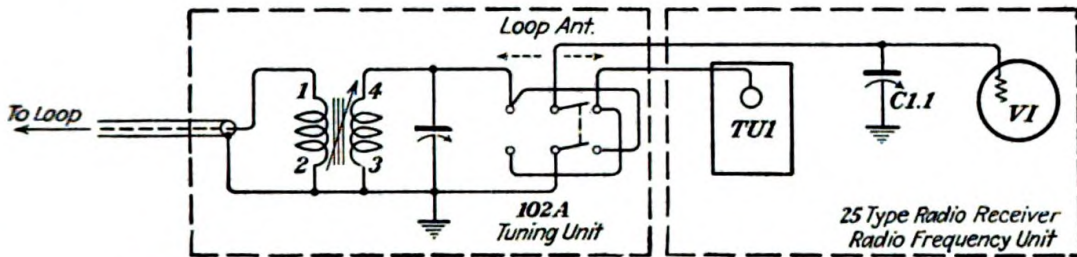


FIG. 9-15.—Method of connecting 102A tuning unit to type 25 receiver.

The condensers whose adjustment screws are marked with red lacquer comprise the oscillator adjustments. Those at the rear of the chassis should be adjusted at the upper ends of their respective frequency bands; those on the coil assembly should be adjusted at the lower ends of the

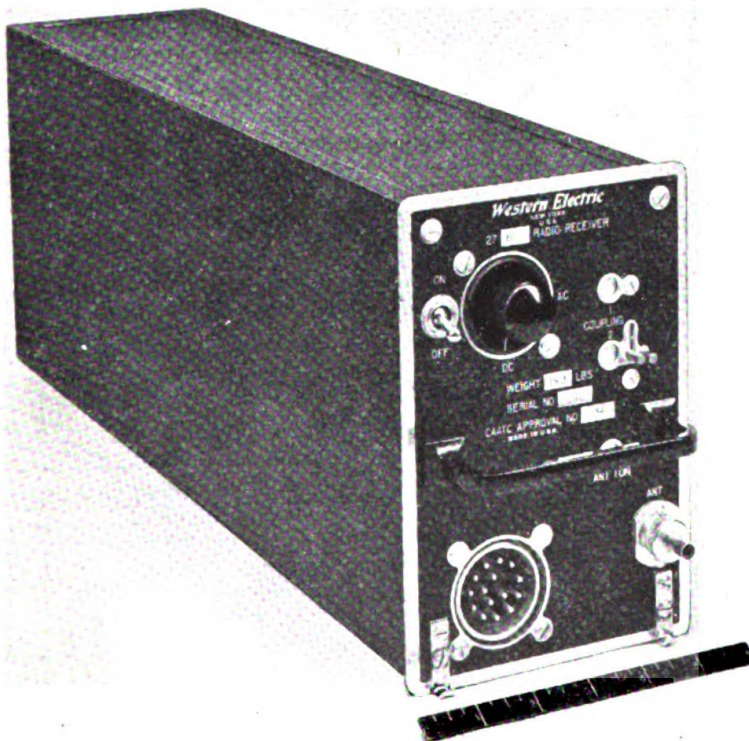


FIG. 9-16A.—Western Electric aircraft marker-beacon receiver 27B.

broadcast and beacon bands only (one pair of adjustments in each band except the high-frequency band, which has only a single adjustment).

9.7. Marker Beacon Ultra-high-frequency Receiver: WESTERN ELECTRIC RADIO RECEIVER No. 27B. a. General Description.—This

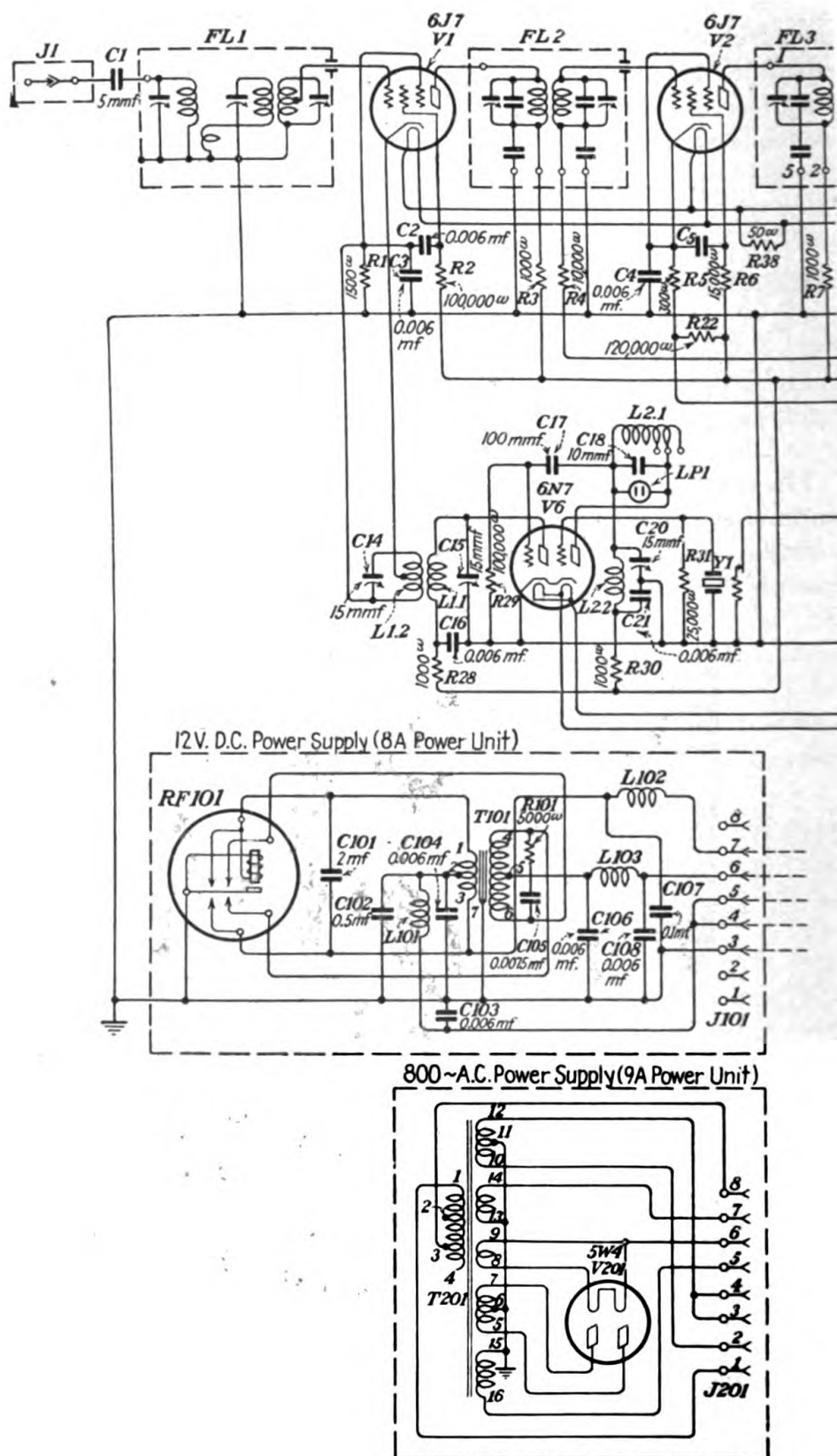
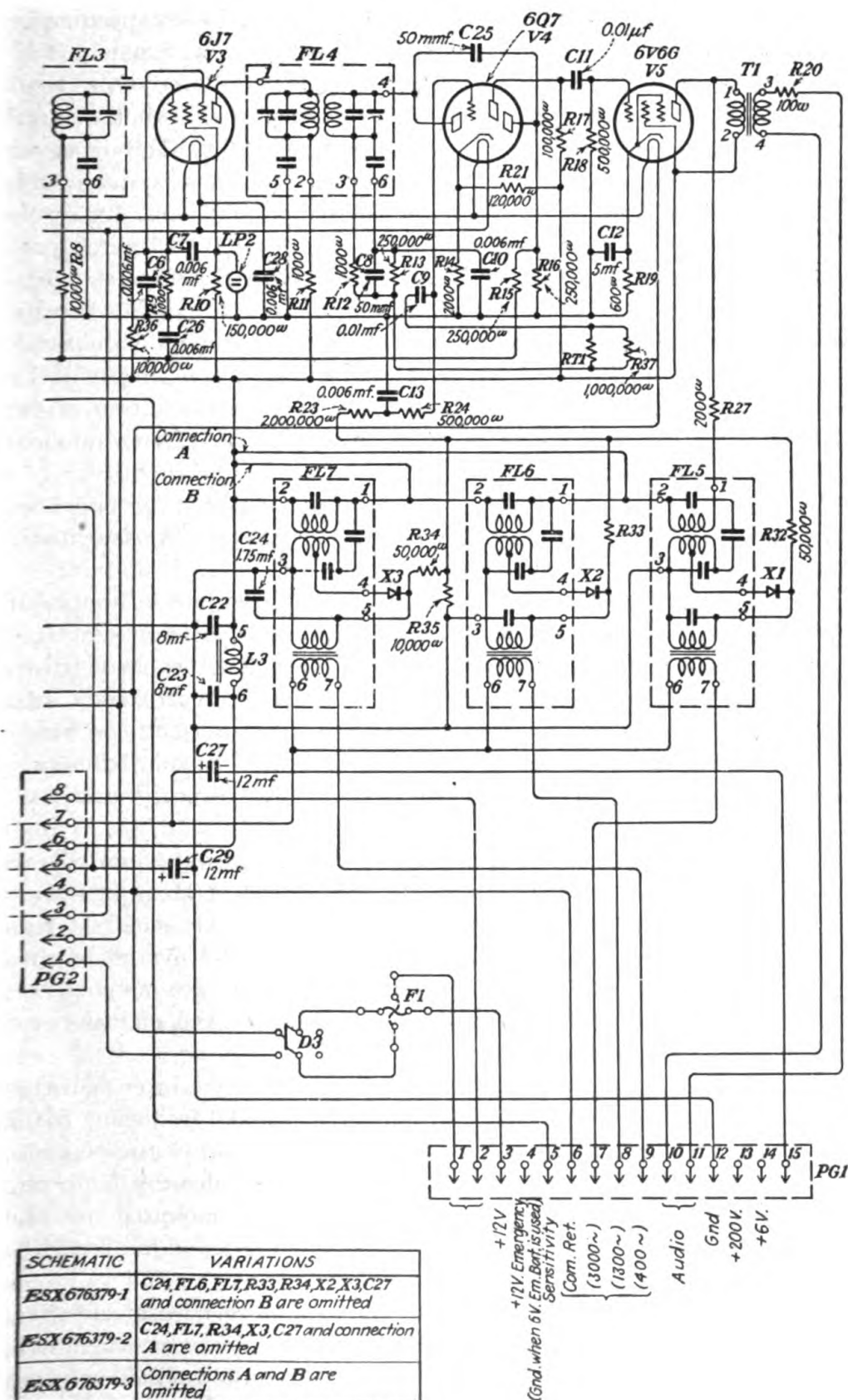


FIG. 9-16B.—Western Electric



27B receiver circuit.

receiver, shown in Fig. 9-16A, is a light, compact set designed specifically for the reception of ultra-high-frequency marker beacon signals. The receiver is a highly selective crystal-controlled superheterodyne unit operating on a fixed frequency of 75 megacycles, providing both visual and aural indication of the signal being received. The 27B receiver can be supplied with one, two, or three audio channels and lamp circuits for operation from signals modulated by 3,000-, 1,300-, and 400-cycle tones. Provisions have been made in the design so that, if the receiver is initially purchased equipped with only the 3,000-cycle channel, additional audio channels for operation from landing marker signals modulated by 1,300- and 400-cycle tones may be readily installed in the field. In an installation in which the three units are used, one lamp will be operated by fan and cone-marker signals, another by signals from outer marker transmitters, and the third lamp by signals from inner marker transmitters.

The 27B receiver differs from the 27A receiver in that it incorporates modifications which result in improved performance. A schematic diagram is shown in Fig. 9-16.

The receiver design provides for two types of internal power supply for normal operation; that is, the 8A power unit which is a 12-volt synchronous vibrator, and the 9A power unit which is a 115-volt 800-cycle rectifier. The power-supply units mount on the rear of the receiver chassis and make the necessary electrical connections by a plug-and-jack combination. The total drain for 12-volt vibrator operation is approximately 3 amp., whereas for 115-volt 800-cycle operation the drain is approximately 65 volt-amp.

The receiver unit consists of a chassis and attached front panel which slides into an over-all box and fastens in place with a Dzus fastener.

Since the power dissipated in the receiver is relatively small, it has been possible to dispense with ventilating louvres in the overall box so that the unit is dust-proof. Four Monel metal buttons are fastened on the rear of the overall box so that the receiver may stand on this end without marring the finish.

The larger pieces of equipment such as vacuum tubes, intermediate-frequency filters, radio-frequency tuning units, and audio-frequency filter units, chokes, and transformers are mounted on the top of the chassis, whereas the smaller parts such as resistors, by-pass condensers, and the oscillator and harmonic generator coil assemblies are mounted on the bottom. All component parts are securely mounted and are readily accessible for servicing.

The tuning controls for the oscillator and harmonic generator circuits, and the intermediate-frequency filters are accessible only when the receiver chassis is out of its overall box. The radio-frequency unit tuning adjustments are made through holes in the front panel which are

provided with a slide cover so that they can be covered up after the tuning adjustments have been made.

The front panel contains the ON-OFF switch, a two-position fuse holder, the antenna connector, the Cannon power plug, and the radio-frequency tuning-unit shutter control. A handle is provided for convenience in handling the receiver.

b. Power-supply Unit.—When operated from a 12-volt direct-current source, the 27B radio receiver uses the 8A power unit. When the supply is 115 volts 800 cycles, the 9A power unit is used. Schematic and wiring diagrams of the 8A and 9A power units are shown in Fig. 9-16B.

The component parts of the two types of power supply used in the 27B radio receiver are assembled on panels designed to mount on the rear of the receiver chassis and become an integral part of the receiver when in place. In order to minimize the time required to change power supplies, a plug and jack arrangement have been provided on the power-supply unit and the receiver chassis so that all electrical connections are made by plugging the unit in place. To complete the change, it is only necessary to bolt the power unit to the receiver chassis. Centering studs and holes are provided so that the plug and jack mesh properly.

c. Description of Circuits.—The input band-pass filter FL_1 consists of three coupled tuned circuits resonating at a frequency of 75 megacycles and designed to match a 70-ohm concentric line to the grid of the first detector. The selectivity of this filter is such that an attenuation of at least 60 db is offered to the image and other undesired frequencies.

An RCA 6J7 vacuum tube V_1 is used as the first detector. Modulation is produced by introducing the signal voltage, from the signal-frequency filter, onto the control grid and introducing the heating oscillator voltage into the cathode circuit. The plate circuit of the modulator is connected to the input of the intermediate-frequency amplifier.

A double-triode vacuum tube V_6 , RCA 6N7, is used as a crystal oscillator and harmonic generator. The crystal Y_1 is in the grid circuit of one of these triodes. The plate circuit of this triode is tuned to the crystal frequency by $L_{2.1}-C_{18}$. The tuned circuit, $L_{2.2}-C_{20}$ in series with $L_{2.1}-C_{18}$, is tuned to the third harmonic of the crystal and drives the grid of the second triode in V_6 . The plate of this second triode is tuned to the ninth harmonic of the crystal frequency by $L_{1.1}-C_{16}$ and is coupled to $L_{1.2}-C_{14}$ in the cathode circuit of the first detector. The neon lamp LP_1 shunted across the fundamental tuned circuit of the crystal oscillator acts as a voltage regulator and tends to keep constant gain when crystals of differing activity are used. The frequency of the crystal to be used is determined by taking one-ninth of the difference frequency of the signal and intermediate frequencies, that is, $\frac{1}{9}$ (75 megacycles - 6.325 megacycles) = crystal frequency = 7,630.5 kilocycles.

The intermediate-frequency amplifier consists of two stages of selective amplification operating at a frequency of 6,325 kilocycles. Three double-tuned circuits coupled to form band-pass filters with a pass-band of about 60 kilocycles are used as coupling elements between the first detector, the two intermediate-frequency amplifier stages, and the second detector. Resistance capacity filters are used to filter the radio-frequency components from the direct-current leads. Cathode resistors are used in the two stages to obtain the necessary fixed bias for proper operation of the vacuum tubes. The fixed tuning capacities of each of the intermediate-frequency filter tuned circuits have temperature coefficients of capacity such that the mid-band frequency of the intermediate-frequency amplifier remains substantially constant for a wide range of variations of ambient temperature.

The circuits that stabilize the receiver for supply-voltage variations are associated with V_3 and consist of a small neon-voltage regulator LP_2 , which regulates the screen voltage of this tube, and a resistor R_{36} which provides a bleeder current through R_9 , the cathode bias resistor of the tube. With this circuit, as the supply voltage increases, the grid bias increases, and since the screen voltage remains substantially constant, the gain of V_3 decreases. The reduction in gain thus produced is adjusted to compensate the normal increase in gain of the rest of the receiver accompanying an increase in supply voltage. An additional improvement is obtained at low supply voltage by connecting R_{36} across one branch of the heater circuit. This resistor slightly unbalances the heater strings in favor of the 6V6 output tube, the gain of which, tests have indicated, falls off more rapidly, with low heater voltage, than the other tubes in the receiver.

Relatively constant gain over a wide range of ambient temperature is obtained by adding a stabilizing network in the grid circuit of the first audio amplifier V_4 . The circuit consists of a Western Electric 1B thermistor, RT_1 , in parallel with a fixed resistor R_{37} , which act as the series arm of an L pad, the shunt arm of which is R_{24} . The thermistor is a resistance element which has a large negative temperature coefficient of resistance. Therefore the loss introduced by the pad varies inversely with temperature. The elements of the pad are so chosen that the overall gain of the receiver remains nearly constant over the temperature range of -40 to $+130^\circ\text{F}$.

The secondary of FL_4 is connected to one of the diodes in V_4 , RCA 6Q7, which serves as the second detector, and is capacitatively coupled to the other diode which acts as the AVC tube. Rectified voltage appears across R_{16} and is fed back to the grids of the two intermediate-frequency amplifier tubes, V_2 and V_3 , to regulate the gain of the receiver, while the audio-frequency component of the signal appears across R_{13} and is applied to the grid of the triode part of V_4 . The audio-frequency

signal is amplified in the triode section and is applied to the grid of V_5 , the second audio-amplifier.

An RCA 6V6 G vacuum tube is used in the second audio-frequency amplifier stage V_5 . The plate circuit of this tube feeds two parallel circuits. One is an output transformer T_1 which provides the headset output and the other the primary of the 3,000-cycle audio filter or, if more than one channel is used, the primaries of the filters connected in series. The output of each filter is applied to a copper oxide rectifier. The rectified direct current from the applied audio-frequency flows in the direct-current winding of a saturable core reactor. An alternating-current winding on this core is in series with the indicating lamp and the light-voltage source. As a result, when the impedance is lowered by saturation, sufficient alternating current flows in this circuit to operate the lamp.

In order to sharpen the response of the lamp to changes in signal input, a feed-back circuit is used which results in a non-linear amplifier. The triode of V_4 is normally biased so that it is operating at reduced gain. R_{23} , the grid filter of this tube, returns to ground through R_{35} . The series combination R_{35} and R_{32} is shunted across the direct-current winding of the saturable core reactor. The polarity of this feed-back connection is such that after a signal is initially received the bias of the triode of V_4 is reduced by an amount equal to the direct-current voltage appearing across R_{35} , thus increasing the gain of the first audio-amplifier.

The receiver is designed to operate from either a 12-volt direct-current source or a 115-volt 800-cycle alternating-current supply. In each case, the receiver high-voltage supply is 225 volts at 55 ma. With a 12-volt primary supply, a synchronous vibrator is used to supply the direct current, whereas with the 115-volt 800-cycle supply a vacuum-tube rectifier using an RCA 5W-4 (V_{201}) is used. Ample filtering is provided in both units to reduce the radio-frequency noise and hum to a negligible amount. Each power-supply unit forms an individual panel which mounts on the rear of the receiver chassis. A plug-and-jack combination is used so that all necessary electrical connections are made when the unit is put in place. Locating studs are provided to facilitate the assembly, which is completed merely by fastening the panel by four bolts.

d. Performance Characteristics.—The maximum sensitivity of the receiver is such that an input of 1,500 μ v or less modulated 30 per cent with 3,000-, 1,300-, or 400-cycle tones will operate the lamps in the indicator unit. This sensitivity is substantially independent of the aural load. Terminal 5 on the power plug PG_1 provides means for controlling the sensitivity of the receiver. When this terminal is grounded, maximum sensitivity is obtained. The sensitivity can be reduced by inserting a resistance between terminal 5 and ground.

At any setting of the gain control, the margin between the signals will produce 4.5 volts across the indicator lamp, and the signal that will produce less than 1.0 volt across the lamp is not more than 3 db. In receivers having only the 3,000-cycle channel, this margin may be adjusted between the limits of about 12 db with no feedback and about 2 db with maximum feedback by a change in the values of R_{32} , R_{35} , and R_{14} . When a receiver is equipped with three channels, the shunting effect of R_{33} and R_{34} must also be considered.

The aural output at the point where the light operates is at least 150 mw. in a 250-ohm non-inductive load.

The selectivity of the intermediate-frequency amplifier is such that at a band width of 60 kilocycles the attenuation is not over 6 db and at 300 kilocycles not less than 60 db.

The image response of the receiver as well as all other undesired responses are at least 60 db down from the desired signal response.

A signal at the intermediate-frequency applied to the input of the receiver is down at least 60 db from the desired signal response.

The signal-to-noise ratio with an input of 150 μ v modulated 30 per cent with 3,000-, 1,300-, or 400-cycle tones and an output of 150 mw. into 250 ohms is at least 30 db.

The *A VC* used is such that a change in input between 150 and 100,000 μ v does not materially change the brilliancy of the light.

The hum level of the receiver is at least 55 db below zero level (6 mw.) measured with standard telephone-line weighting.

With a supply-voltage variation of 10 to 15 volts, the overall gain change does not exceed about 2 db.

Over the temperature range of -40 to $+130^{\circ}\text{F.}$, the overall gain variation is ± 2 db.

e. Tuning Instructions.—The 27B radio receiver as received from the manufacturer is ready for operation, having been completely aligned, tested, and tuned in the manufacturer's plant. The only normal tuning adjustment which should have to be made when the receiver is connected is to align the signal frequency filter FL_1 to the plane's antenna. This can be conveniently accomplished on the ground by radiating a modulated 75-megacycle signal from a Ferris 18B signal generator or its equivalent to the antenna. This signal can be used to check the antenna tuning and the tuning of the secondary and tertiary circuits of FL_1 . These controls are adjusted from the front panel and are designated thereon as ANTENNA TUNING and COUPLING 1 and 2. The antenna circuit is so marked. Coupling 2 is the secondary circuit and coupling 1 the tertiary circuit. If desired, the tuning of the harmonic generator circuits can also be checked at this time by adjusting the oscillator-harmonic generator tuning controls 1, 2, and 3 for maximum drop across the first-detector plate-filter resistor R_3 . In order to facilitate this adjustment, an auxiliary

terminal strip, terminating the two sides of this resistor, has been provided. A high-resistance voltmeter should be used for this adjustment.

If for some reason it is necessary to retune this receiver completely, procedure should be as follows. A modulated intermediate-frequency signal of 6,325 kilocycles should be applied to the grid of the modulator tube V_1 . A headset or an output meter should be provided to give an aural or a visual indication of the receiver output. The signal generator should be adjusted for its maximum output, and the tuning condensers of the intermediate-frequency filters FL_1 , FL_2 , and FL_3 should be adjusted for either maximum audible signal or meter deflection. After the filter units are brought into resonance, the input signal should be progressively reduced until at the final adjustment a small signal is being used so that a sharp indication of tuning is obtained. If meter deflection tuning is being used, the final tuning adjustment should be made with a signal giving an audio-output deflection of approximately one-fourth of the maximum output deflection.

After completing the alignment of the intermediate-frequency amplifier, it will be necessary to align the oscillator, harmonic-generator, and signal-filter circuits. The fundamental crystal circuit is a fixed tuned circuit consisting of $L_{2.1}$ and C_{18} . Taps on the winding $L_{2.1}$ are provided to allow adjustment of this circuit. A neon lamp regulator is shunted across the circuit and should be glowing if the crystal is in place and the oscillator is functioning properly. The oscillator-harmonic generator circuits 3, 2, and 1 should be adjusted by means of the meter previously mentioned in the order named. It is possible under certain conditions to obtain two positions that give a maximum when tuning oscillator-harmonic generator circuit 3. The correct one is that which the tuning of circuits numbers 1 and 2 effects. Recheck each tuning for the final alignment. After completing this alignment, introduce a modulated 75-megacycle signal of 100,000 μv into the antenna plug. If the signal is not heard, check the tuning of the signal generator. After the signal is heard, adjust the antenna tuning and couplings 1 and 2, and reduce the signal generator output progressively to obtain sharp tuning indications. When these circuits have been approximately tuned, carefully retune the signal generator and check the tuning of all the input filter circuits. After installation in a plane, the antenna-circuit tuning should be checked with the ship's antenna connected to the receiver as described above.

f. Maintenance Instructions.—Since continuity of service is of prime importance in the service for which these receivers are to be used, it is desirable to establish test benches at divisional headquarters or other strategic points for routine checking of the receivers at regular intervals. By keeping complete records of the individual receiver performance during these check tests, it should be possible to anticipate failures and thereby avoid interruptions of service.

For the test-bench set-up, it will only be necessary to duplicate the equipment of a plane installation. A Ferris 18B standard signal generator equipped with high-frequency coils and with provisions for external modulation is a suitable source of high-frequency signals. An audio oscillator capable of modulating the 18B signal generator 30 per cent at 3,000, 1,300, and 400 cycles will also be required. A multi-purpose analyzer of the high-resistance voltmeter type will be needed for voltage measurements.

Direct-current voltage checks on the receiver should be made with the sensitivity control in the maximum position and using a 1,000-ohm per volt voltmeter. Alternating-current voltage measurements can be made with a rectifier-type voltmeter.

The vacuum tubes can be checked by measuring them on a mutual conductance bridge and comparing the results with the published data for the types in question.

If one of the copper oxide rectifiers is suspected of being bad, its condition can be determined either by replacing it with a unit known to be in good condition and noting the effect on the set's performance, or by test. To test the unit, disconnect it and apply 7.5-volt direct current across the unit, with the positive terminal of the test voltage connected to the positive terminal of the rectifier. Under these conditions with the unit in question, the current should not exceed 1.6 ma.

Note on Aviation Headphones.—To provide a headset that will give some relief from unpleasant clicks, sudden loud signals, or bursts of static a receiver using a damped diaphragm has been designed and manufactured by Western Electric. This headset, known as the 1019A headset, has been approved by the Civil Aeronautics Administration. It consists of two receivers connected in series. Each receiver has a direct-current resistance of 60 ohms and an impedance of 250 ohms at a frequency of 800 cycles. The receivers are mounted in a flexible headband and are equipped with a cord having a plug-wired tip and sleeve.

9.8. Aircraft Antennas.—A number of different forms of antennas are used on aircraft, the type used depending on the service to which it is to be put and the type of plane in which it is installed. Generally speaking, airplane antennas divide into two classes, namely, the fixed or rigid type and the trailing-wire type. A number of factors function to determine the selection of the antenna to be used on a given plane. It may be necessary to use more than one antenna under special circumstances; a beacon receiver utilizing one of several types, a direction finder utilizing a loop and, if transmission from the plane is to be accomplished, still another set of provisions must be fulfilled. All the antennas described and referred to as being illustrated, are shown in Fig. 9-17.

1. **FIXED TYPES.**—*a.* The inclined antenna shown in (a) is supported between the tail surface and the forward part of the fuselage. It may or

may not be supported on the forward end by a short stub mast 10 in. or 1 ft. high.

b. The doublet antenna may be erected on an airplane as shown in (b), the ends of the wings and the tail being used for supports. If desired, a short mast about 5 ft. high may be erected in the rear of the fuselage just forward of the tail to which the antenna may be fastened instead of to the tail surfaces. When this is done, the antenna leadin may be brought down through a hollow supporting mast.

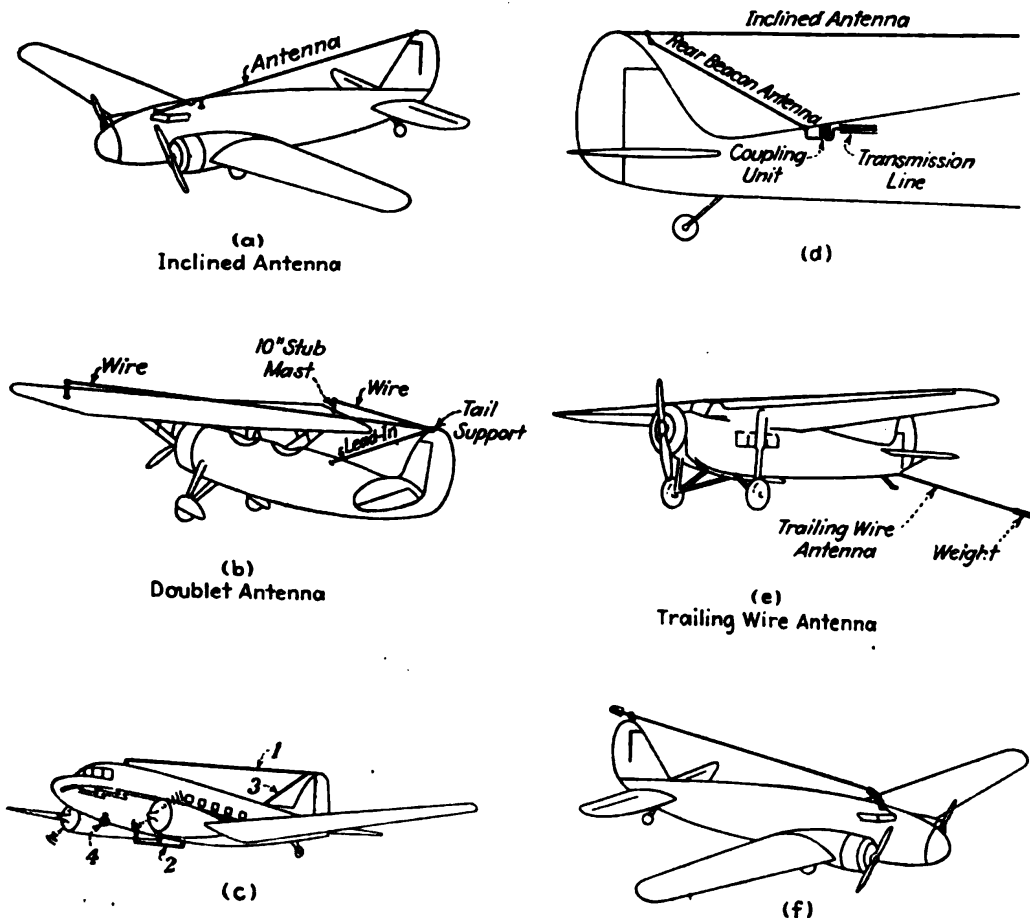


FIG. 9-17.—Types of aircraft antennas.

c. The single-wire antenna (2, diagram c) parallel to the fuselage is the type most generally used for beacon reception for the purpose of making instrument approaches. For best results, the antenna should be approximately 12 ft. long with the leadin tapped off exactly in the center. Wherever possible, the antenna should be on the underside of the aircraft and should be extended along the center of the plane. This type antenna is of low sensitivity which makes it ideal for definitely determining when over a "cone of silence." It is seldom used for long-distance reception.

d. On large aircraft, a single-wire antenna from the rudder standard to a point on the fuselage approximately 10 ft. forward of the rudder is

used for long-distance beacon reception. The end of the antenna at the fuselage forms the leadin. This is illustrated in diagram (d) and is called a rear-beacon antenna.

e. Antenna coupling units are used extensively on aircraft to provide maximum sensitivity with short antennas. Such units consist of impedance-matching transformers which match the fixed antennas to impedance of transmission lines. A similar unit is then used at each receiver to couple the transmission line to the input circuit. In this way, any of the receivers may be used on any of the antennas without changing the input impedance. Suitable switching arrangements are provided for this purpose.

2. TRAILING WIRE TYPES.—There are several different types of trailing-wire antennas. All of them are used primarily for transmission and reception in the communications band. A description of each follows:

a. "Bomb type" is the name applied to those antennas which use weights for the purpose of extending the wire to the rear of the aircraft. The wire is on a reel and extends through an insulated tube in the lower side of the fuselage, thence to an eye insulator on the landing-wheel strut. The end of the wire is weighted and stops at the strut insulator when reeled in. It cannot be used on the ground and *must* be reeled in prior to landing. While in flight, the antenna may be let out for use and, by unreeling to a point marked on the reel after the initial tuning, maximum results will be obtained.

The usual practice with this type of antenna is to use it as a quarter-wave antenna. Although it is advisable to "touch up" the tuning in flight when first determining the length of wire to be unreeled for quarter-wave operation, very good results may be obtained by tuning the transmitter on the ground with a dummy antenna.

The antenna is let out in flight until maximum loading is indicated. There are a number of factors that may give a false indication of maximum loading. However, it will usually be found that little or no further tuning is necessary when this method is used. It is then a simple matter to mark the reel so that the antenna may be let out to the same length each time.

Owing to the danger of damage from the weight and the fact that this type cannot be used on the ground, it has become a very infrequent installation. This type of antenna is shown in diagram (e).

b. Some trailing-wire antennas extend from the transmitter through the inside of the aircraft and thence through the tail in an insulated tube. A small rubber wind sock is attached to the end of the wire and extends the wire when in use. Like the bomb type, this antenna employs a reel, and the same methods of tuning are applicable. The main disadvantages, and the ones that have caused it to be little used are: it cannot be used on

the ground, and because of the long insulated tube it easily becomes fouled.

c. The overhead trailing-wire antenna [diagram (f)] is the most popular and is used extensively on small aircraft. The wire extends through the upper side of the fuselage in the forward part of the plane. An insulated tube, which extends about 6 in. outside the fuselage, provides the means of exit. The wire then extends through an eye insulator located on the rudder, or rudder standard, and attaches to a rubber wind sock. The eye insulator serves as a stop when the sock is reeled all the way in. The same methods of tuning apply as with the two foregoing types.

The main advantages of this type are: the antenna seldom fouls, as only a short length of tubing is usually necessary; when reeled in, the overhead portion is available for use which provides ground transmission. When used with a loading coil which can be switched in or out of the circuit, this antenna is quite suitable for communications with control towers when on the ground or in the vicinity of the tower using only the overhead portion. When greater range is required, the loading coil is cut out and the antenna reeled out to the proper length.

d. The fixed length trailing-wire antenna is now practically obsolete. When used, it consists of a fixed length of wire dependent upon the size of the aircraft and the transmitter installation. This is usually coupled to a transmission line by means of an impedance-matching coil, and the transmission line runs direct to the transmitter output. The principal disadvantages are that the antenna or part of it is frequently lost while landing or taking off. The loss may be caused by the wire catching on ground obstacles or by the whipping effect caused by high aircraft speed. When part of the antenna is lost, the entire installation is off tune.

3. DIRECTION-FINDER ANTENNAS.—Aural-null direction finders employ single loops which are of two types: encased in an aluminum case, except for a small portion at the opposite side of the loop from the loop drive, which is waterproofed; a plain loop encased in a streamlined housing designed to cut down wind resistance. The loops may be mounted either on the upper or lower side of the aircraft, but the control unit for turning the loop *must* be properly designed for the place of mounting. A control unit designed for upper mounting cannot be used for lower mounting as the loop and azimuth would turn in opposite directions.

Radio compasses and automatic direction finders (see Sec. 9.15d) require two antennas. The radio compass employs either a fixed or rotating single loop of conventional type and a single-wire center-fed "sense antenna" [antennas 2 and 4, diagram (c)]. Automatic direction finders use motor-driven crossed loops (two separate loops at right angles to one another) housed in a streamlined case and a V-shaped sense antenna usually extending from the nose to either landing-gear support.

4. **GENERAL.**—For the most part, transport aircraft [diagram (c)] use the overhead inclined antenna (1) for transmission and reception in the communications band. They use the short single-wire antenna (2) on the underside for instrument approaches and the rear single wire (3) for distant reception on the beacon band. They also use the crossed loops and V sense antenna for direction finding. This type of aircraft seldom employs trailing-wire antennas of any type.

Small aircraft generally employ the single-wire antenna on the underside for instrument approaches and the overhead trailing wire (with reel) for transmission and distant beacon reception. This type of aircraft transmits on 3,105 and 6,210 kilocycles but seldom has occasion to receive signals except in the beacon band.

Reels used with trailing-wire antennas are usually mounted in the cockpit adjacent to the point where the wire goes through the fuselage. High-tension wire is used between the transmitter and the reel, and electrical contact to the antenna is provided by means of a sliding contact on the reel, which maintains a slight tension on the antenna as it is reeled in or out.

9.9. Aircraft Shielding and Bonding. *a. Requirements.*—The improved design of modern aircraft receiving equipment has reduced, to practically a minimum degree, the problem of noisy reception due to the receiver design itself. This is primarily due to the great care exercised by manufacturers in the magnetic shielding of all radio-frequency coils and internal wiring, introduction of grid and plate filtering in all stages, AVC, interstation noise suppression, tube design, mechanical rigidity, and the complete shielding of the entire receiver. If the receiver incorporates all these improvements, particularly complete exterior shielding, it will be impossible for it to pick up any stray electrostatic or magnetic fields produced by exterior ignition or contact interruption caused by switches, loose connections, high-frequency contact variation, or any other source of impulse excitation. However, when the antenna or loop system is connected to the receiver, all such electrical disturbances will be picked up by the antenna or loop and amplified through the receiver.

The problem, therefore, with completely shielded receivers, is the elimination of noise interference at the source rather than in the receiver itself. Hence, great care must be exercised to reduce electromagnetic radiation from all undesirable sources by thorough shielding of all ignition wires, spark plugs, spark coils, lighting wiring, electrical indicating devices and associated wiring, good electrical connections, and by thorough grounding of all shields to a common ground connection. The importance of connecting all metal parts to a common ground is extremely vital since any variation between metal parts, caused by a high-resistance contact or connection, will produce a potential difference between the two or more contacts which may result in electrostatic or electromagnetic

radiations which are picked up by the antenna or loop system and amplified.

b. Shielding.—The principal function of electrical shielding in receiving circuits, as previously pointed out, is to prevent inter-circuit magnetic and electrostatic reactions and the picking up of highly damped electrical surges or impulses. In aircraft (and automobile) radio systems, the latter is of the most vital importance since it is the source of external electrical disturbances. Consequently, if the radiation of highly damped electromagnetic radiations is suppressed at the source, interference due to these may be practically eliminated. These radiations in aircraft (and automobiles) are primarily due to the spark-ignition system and its associated electrical connections, the generator circuits and the lighting circuits. At any point in which electrical circuits are broken because of the opening of switches, the production of sparks, and the variation of magnetic fields, such as in the generator commutator, highly damped waves are radiated into space or along conducting wires. Hence, all radiations must be suppressed or limited to the confines of the sources creating them. This may be accomplished as follows.

The high-tension system including either the magneto or coil systems should be placed in a complete metal housing. The leads should be enclosed in a continuous metal sheath extending from the housing to their point of termination. Each individual lead for the spark plugs should be encased in a flexible copper-braided shield, the braided shield to be soldered to the manifold all around the holes through which the wires pass. If the leads emerge from an insulating block, this block should be covered with a metal shield or can. All braids must be soldered to the can around the hole through which the wire emerges. All braiding or piping must make contact with the engine metal and chassis at as many points as possible. These contacts should be made by short lengths of pigtail braiding or copper stripping thoroughly soldered to the points of connection.

All spark plugs must be enclosed in a properly designed shield housing possessing a complete metallic circuit, each shield to be soldered to a copper braid or strip and grounded to the engine frame and chassis.

All leads in the low-tension system including the light wiring, instrument-board connections, and generator must be similarly shielded and grounded to the engine frame and chassis. The instrument board and battery should be thoroughly encased in a copper housing and grounded.

There are available complete ignition harnesses enclosed in flexible braiding. These should be additionally encased in a pipe manifold to increase mechanical rigidity and protection; both harness and piping to be thoroughly grounded.

Summarizing, it may readily be seen that the thorough elimination of radiation and pickup is almost entirely dependent upon complete shield-

ing and frequent grounding of all wires and component parts. If the entire engine and all parts are thus thoroughly shielded and grounded, complete interference elimination may be approached.

c. Bonding.—This term refers to the interconnection of all metal parts in the aircraft to a common point or ground (chassis), in such a manner as to provide a path of extremely low resistance to the flow of any high-frequency currents which may be developed by the accumulation of electrostatic charges. If charges are accumulated between two or more metals, because of resistance between them, the electric field produced will be stationary and no radiation will result. If, however the resistance between these metals is varied owing to vibration or rubbing, the friction will produce a variation in the contact resistance which will produce a movement of the electrostatic field resulting in the radiation of a highly damped (broad) wave or pulse of high frequency. It is possible that the electrostatic accumulations between metals due to poor contact may develop an electrostatic field or e.m.f. sufficiently high to cause a spark to jump between the contacts or to an adjacent conductor. This will result not only in severe pulse radiation but will also introduce a serious fire hazard.

In wooden airplanes, therefore, it is necessary to provide metal strips of copper about $\frac{1}{4}$ by $\frac{1}{64}$ in. or larger along the front and rear spars from the fuselage to the wing tips. These strips must be connected from the engine base or metal chassis to the internal brace wires at each drag brace, to the external brace wires and fittings wherever the wires and fittings come into the wing, and to each other by similar strips which run from the front and rear strips along each drag brace. The front and rear strips must also be connected together at the wing tip. All brace wires or any other movable or semimovable parts which come into actual electrical contact with each other, or with other metal parts of the ship, must be thoroughly connected. Where wires are very close but no actual contact exists, insulation must be provided to prevent these parts from touching because of vibration.

Turnbuckles and tie-rod terminals should be bridged by a flexible copper braid and grounded to prevent high-resistance contacts from developing between them. Usually these contacts are quite secure and introduce practically no resistance, in which circumstances no shunting braid is required. These connections should be tested frequently, however, owing to the possibility of high-resistance formation from moisture and corrosion. All water, gasoline, and oil lines must be grounded to the metal chassis at intervals. Rubber-hose joints must be bridged by copper-braid strips to insure against the metal pipes on either end of the hose being at different electrical potentials. All metal hinges, control wires, elevators, ailerons, bolts, and screws must be grounded to the chassis. In metal planes bonding is unnecessary, but all inter-

connecting plates, control wires, bolts, and electrical wiring metal cables must be connected by copper braids or welding. If metal parts are separated for shellacing, they must be carefully scraped and cleaned when reassembling.

The thoroughness of the bonding and grounding between various metals and the chassis can be determined by the use of an ohmmeter and a battery. All metal parts should indicate a full-scale reading (0 ohms), when the meter is connected across the chassis and the individual parts under test. If long test leads are used with the meter, an exact value of the lead resistance must first be determined to avoid erroneous readings. A small flashlight test lamp or buzzer may also be used by connecting either one of them in series with a small battery to one side of the metal under test and the other side to the chassis. If these tests are made while the motor is running, to produce vibration, an accurate indication of the efficiency of the bonding may be ascertained. If the lamp or buzzer is intermittent in its operation, it is quite evident that the grounding is poor. Care should be exercised that no sparks are produced when using the lamp or buzzer. It is advisable to use an ohmmeter when making tests for proper grounding when the motor is in operation.

The component parts which must be bonded may thus be summarized as follows:

- a. All metal tubing and cables from the ignition system.
- b. All connecting wires leading to the radio-receiver instrument panels, electrical lighting.
- c. All spark-plug caps and shielding cans.

All of these parts *must* be bonded to a common point through a low-resistance conducting strip or braid to avoid potential gradients between various grounded portions. If possible, the bonding should be made in even sequence at every 7 or 8 in.

III. RADIO AIDS TO AVIGATION

Aeronautical radio-range systems have used loops as transmitting antennas with fair success in the directive transmission of radio waves over short distances. The original installations over American airways utilized these loop transmitting antennas. The wave beams were particularly steady in their directive properties during the day using loop antennas but unfortunately were relatively inaccurate at night owing to phase displacements and shifts due to wave reflections of an uneven character from the Kennelly-Heaviside layer. This variation in wave strength is called the *night effect* and has already been fully explained in Chap. 7.

The night effect is particularly active in mountainous areas and even over flat ground when the distances exceed 30 miles or more from the beacon. A most important development for the elimination of night

effect has been the T-L antenna system which was developed by the Bureau of Air Commerce, U.S. Department of Commerce, and which will be explained in detail later. This system provides a satisfactory beacon course throughout the entire distance range of the beacon with negligible night effect. As loop transmitting antennas may sometimes be used for such purposes as runway-localizing beacons for landing purposes where the range is only about 10 miles and night effect is not involved, its theoretical operation will be explained. The explanation which follows has to do with the loop as used in these radio-range beacons and the results of night effect.

9.10. Action of Loop Transmitting Antennas.—The fundamental principle of directive transmission is simply one in which the transmitted energy is trajected into

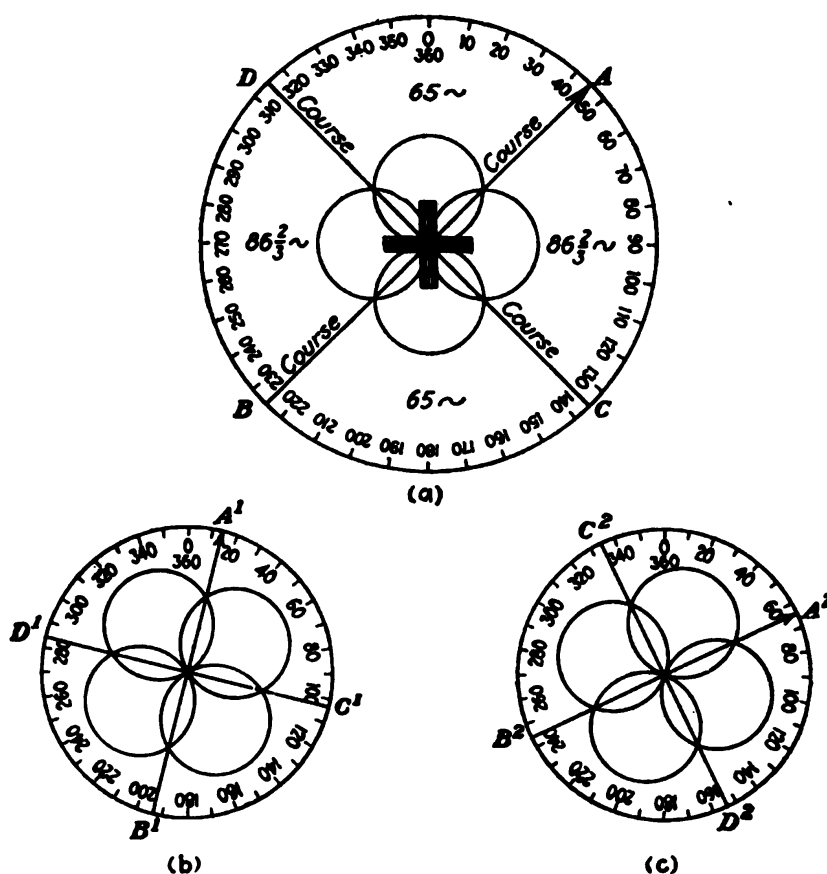


FIG. 9-18.—Effect of Kennelly-Heaviside layer on loop's figure-of-eight pattern.

four beams or paths representing the four major points of a compass, namely, north, south, east, and west. A plane flying in one of these paths or beams is so equipped as to receive the energy by either a visual or an aural electromagnetic system of wave indication. This incorporates the general principles of receiving circuits together with special aural and visual indicators. The special adaptation of loop antennas to directional reception was covered in Sec. 7.13 and will be further treated in Sec. 9.14.

If four waves are directionally transmitted into the north, south, east, and west directions by a system of parabolic reflection antennas, loop antennas, or vertical radiators and each wave differentiated from the other by a standardized code-signal identification, the flight course may be readily determined. This is known as the

aural method of beam identification and utilizes the Morse code of dots and dashes. On the other hand, if the four waves are transmitted at two different modulated or *tone* frequencies somewhere in the low-frequency range between 60 and 100 cycles, these frequencies, when amplified, may be made to vibrate small metallic reeds or ribbons on a visual indicator. This is known as the *visual method* of beam identification.

The transmission of beams in the radio-range beacon system was first carried on by two loops placed at right angles to each other as illustrated in Fig. 9-18(a). These two loops when energized by a vacuum-tube transmitter produce two figure-of-eight field patterns in conformity with the general theory of loop antennas previously explained. These two patterns produce a directional characteristic in four directions, as illustrated, and represent the four beacon courses. This condition is ideally represented during the daytime periods, since the waves do not penetrate into the Kennelly-Heaviside layer and consequently are not subject to reflections. In the night periods, however, between sunset and sunrise, these waves are reflected back to earth so that the ground and sky waves meet at some remote point from the transmitter. This is particularly true during winter nights because of the greater rate of change in the height of the reflecting layer. In other words, as the distance from the transmitter increases, there is a greater reduction of the ground wave, and, consequently, the ratio of the horizontal (sky) to the vertical (ground) signal component at the receiving end is much greater. This difficulty may be somewhat reduced at the receiving end by the use of a vertical antenna, which is much more effective to the low-angle radiation along the earth (vertical component) than to the reflected or high-angle radiation from the Kennelly-Heaviside layer.

The effect of the reflecting layer upon the received signal is therefore the same as if the two loops at the transmitting station were being oriented in different directions, that is to say, as if the beam were being continuously shifted. The effect at the receiving end is the same as if the loops' figure-of-eight patterns had actually been changed from the position (a) to the position (b) or (c) in Fig. 9-18. Obviously, the results at the receiving end would show "off-course" indications anywhere between position (a) and position (b) or (c). For example, it will be noted from the diagrams that the direction of the beacon wave or course will be at the points of the intersection of the two figure-of-eight patterns. Hence, if the direction of the four courses is represented by the letters A, B, C, and D as in the first position, the direction will effectively change at the receiving end just as if the loops were changed to the second position, and the beacon wave will be in the direction of the letters A¹, B¹, C¹, and D¹ or A², B², C², and D². It must be borne in mind that the loops themselves at the transmitting point have not oriented physically but are merely here placed in this position diagrammatically to show the results that may be expected at the receiving end because of the so-called *night effect*.

It is apparent therefore that the night effects may be reduced to only a negligible degree by the use of a radiation system in which the horizontal-radiation component is decreased to a minimum degree such as is obtained with the transmission-line type of antenna next to be explained.

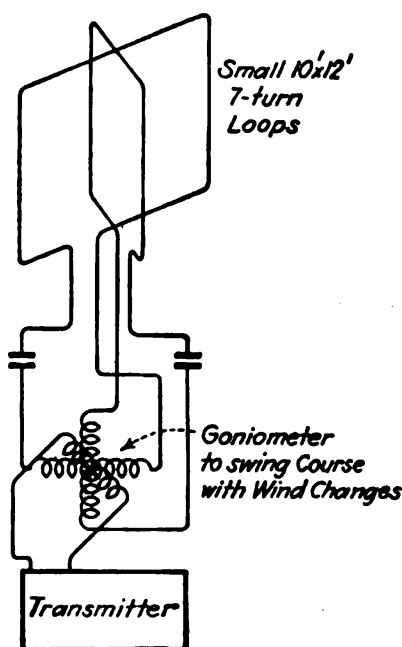


FIG. 9-19.—Radio-range beacon system of loop antennas.

A schematic diagram of a type of radio-range beacon system of loop antennas is shown in Fig. 9-19.

9.11. Transmission-line (T-L) Antenna System.—The arrangement of a transmission-line antenna system is graphically shown in Fig. 9-20. The antenna comprises four vertical antennas which are placed at the corners of a square. This arrangement supplements the loop antennas used in the earlier beacon systems. The four vertical radiators are excited from a tube transmitter through a loop or goniometer system, properly phased, and a transmission line. All units are completely shielded to prevent the radiation of waves from any of the component parts. With the proper adjustments of all circuits it is found, for example, that, if the normal range of the antenna and transmitter is 100

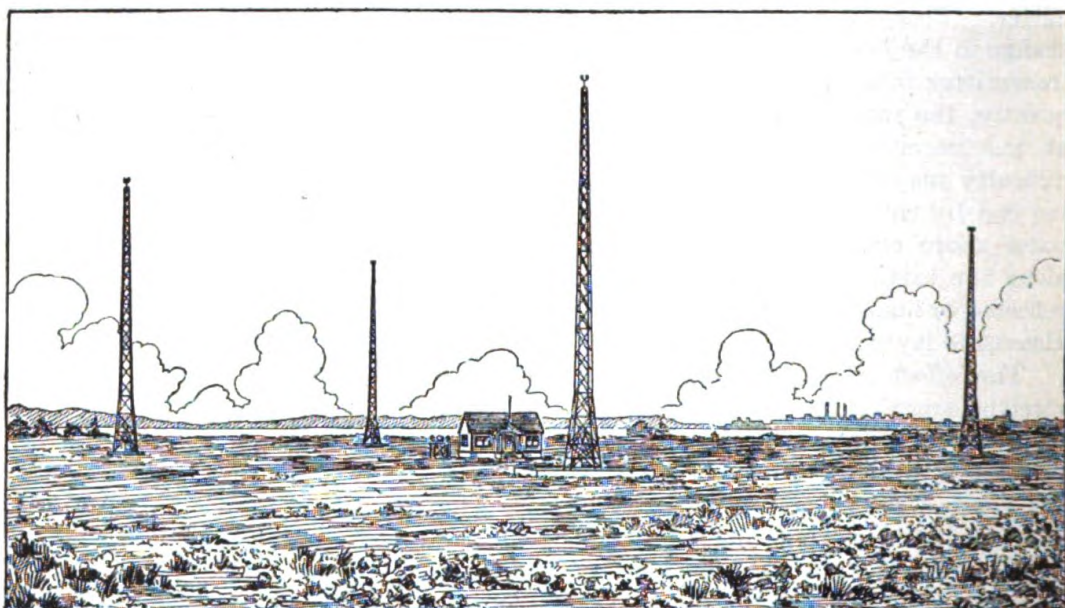


FIG. 9-20.—Topographical layout of transmission-line (T-L) antenna system for beacon system. (Courtesy of Air Commerce Bulletin.)

miles, practically no night effect is detected at this distance with the transmission-line system, while, with the double-loop antenna and a transmitter, having the same transmission range, the night effect is noticeable at almost any point beyond 30 miles. Readings become extremely erratic, and course indications are generally inaccurate. The variations when using the double loop beyond the 30-mile point average ± 30 degrees, while, with the transmission-line antenna, the variations are less than 4 degrees.

Other advantages obtained by the transmission-line antenna system are the simplification of the problem of adjusting the four beacon courses to the arbitrary angles required by the radio waves radiating from it. Rigid adjustments are made to assure the proper adjustments of the phases and for continued stability. This antenna also provides better performance of both radiotelephone and beacon signals.

The development of the transmission-line antenna for low-angle radiation and directional transmission was based upon the fundamental experimenting of Adcock and Eckersley with vertical radiators such as are illustrated in Fig. 9-21. In this system the transmitting circuit output feeds energy into a transmission line in such a manner that the two vertical antennas receive voltages 180 degrees out of phase with each other, so that the current flowing in each vertical antenna is in an opposite direction to that in the other antenna. This results in a magnetic disturbance about each antenna equivalent to the disturbance produced by the vertical wires of a loop antenna, but, since no horizontal portion is present as in the loop, little or no energy is radiated in the horizontal plane. The only portion of the two vertical-radiator systems in which horizontal radiation might take place is that of the two parallel feeding wires or transmission lines, but, since the current is flowing in opposite

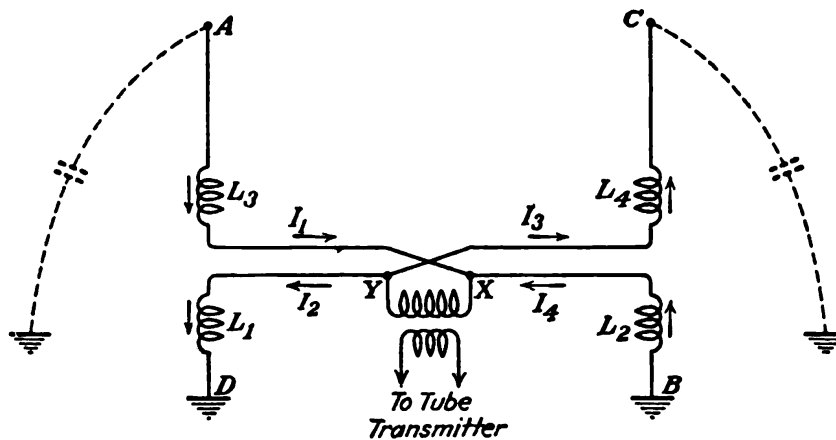


FIG. 9-21.—Adcock-Eckersley experiment with vertical radiators.

directions in these two wires, the magnetic fields about them will cancel each other. However, to insure the complete cancellation of the magnetic field to prevent horizontal radiation, the currents in the two transmission lines must be of equal values, that is, I_1 must be equal to I_2 , and I_3 must be equal to I_4 . To satisfy this condition, critical adjustments of the impedances must be made so that the portion of the circuit from X to A must have an impedance equal to that of the portion from X to B . Similarly, the impedance from the point Y to C must be equal to that between the points Y and D . This condition may be obtained by inserting balancing impedances L_1 and L_2 in the vertical portions of the ground leads B and D . However, the difficulty encountered in obtaining a critical impedance match and the resultant increase of the circuit resistance due to this impedance reduce the efficiency of the entire system to a marked degree. In the vertical-radiator systems each antenna is tuned in the conventional manner by series-loading inductances L_3 and L_4 , respectively.

the primary coupling coils. In other words, the impedance looking into the line must be matched by an equal impedance looking out of the line in order that all the power transmitted by the line be absorbed by the primary antenna coupling coils L_{15} , L_{16} , L_{17} , and L_{18} to prevent line reflections or standing waves which would result in radiations from the transmission line and seriously affect the desired four directional patterns of the vertical radiators. The impedance of the lines used in the transmission-line system is 80 ohms. In order to fulfill the condition of impedance matching, each secondary is calculated to have an impedance of 80 ohms which functions into the transmission line and a primary antenna-coupling impedance of the same value. When the lines are properly adjusted to these values, the radio-frequency ammeters in each line will read exactly the same. With the proper adjustment of the antenna circuit to resonance by the variation of the antenna-tuning inductances L_{20} , L_{21} , L_{22} , and L_{23} , the maximum power will be absorbed and radiated by the four vertical-

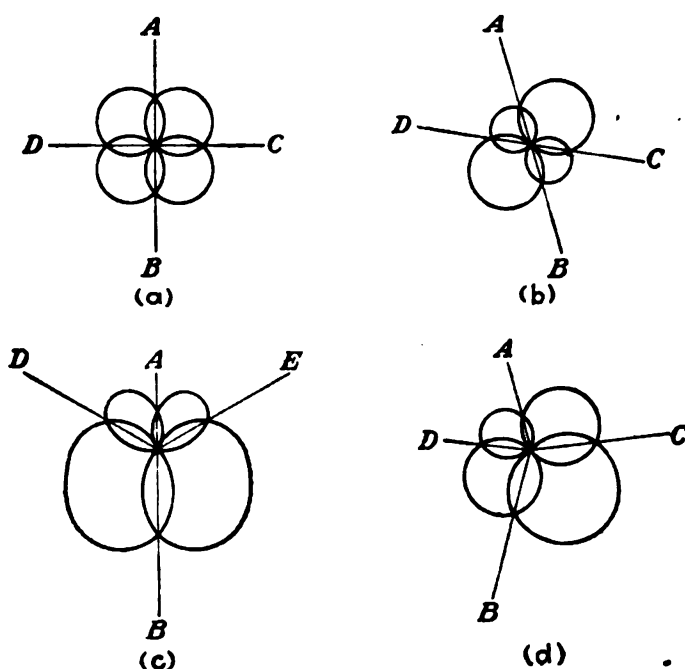


FIG. 9-23.—Field pattern variations, transmission-line system.

antenna systems. This condition will be indicated by a maximum reading on the antenna ammeters, but great care must be taken when the antenna is tuned so that the impedance reflected into the primary coupling coils does not upset the impedance match of those windings. In other words the impedance looking into the primary windings L_{15} , L_{16} , L_{17} , and L_{18} (80 ohms each) must not be altered by the effect of the magnetic coupling reactions from the secondaries back into the primaries.

If all of these conditions are properly fulfilled, the proper time-phase angle of 180 degrees may be obtained between the currents in the two vertical antennas of each pair, and a true figure-of-eight pattern is obtained.

Figure 9-23 illustrates the various patterns produced by varying either the time-phase angle or the intensity of the currents flowing in the four vertical antennas. In this manner any one of the four conditions of course alignment shown may be obtained:

The normal space pattern for a given beacon in which two pairs of 180-degree courses AB and CD are produced at right angles is shown at a .

The condition in which the two courses are no longer at right angles or 90 degrees is shown at b .

The condition in which the 180-degree relationship of one pair of courses is changed is shown at *c*.

The condition in which the courses *AB* and *CD* are changed from the 180-degree relationship is shown at *d*.

The last two conditions *c* and *d* are obtained by shifting the time-phase angle between the currents in the two antennas of a given pair by inserting a variable reactance (X_L or X_C) at the output of L_1 , or L_2 (Fig. 9-22) in series with either one of the transmission lines which feed the two antennas. The second condition, *b*, is obtained simply by reducing the energy in one of the transmission lines by introducing a resistance at the amplifier output of that particular branch.

It is apparent, therefore, that the time-phase angle of the beacon courses into space can be quickly varied so that a rapid phase check and alteration can be made if desired. This is accomplished by placing a sensitive thermocouple in one lead of a given pair of antennas and removing the excitation from the transmission line into this particular antenna system. Now, if the other pair of antennas are excited by their transmission lines, some current will be induced into the unexcited pair since they represent tuned or resonant absorbing circuits. Consequently, if the current induced into these antennas is zero, it is a true indication that the phase angle between the two pairs must be exactly 180 degrees. On the other hand, however, if the indicator shows a flow of current, it is apparent that the phase angle lies somewhere between +180 degrees and -180 degrees. The exact amount of 180-degree phase departure between antennas may thus be accurately determined by a meter which reads the actual angular variation in degrees.

This instrument may be a milliammeter located in the transmitter room and energized by a separate pair of underground triple-shielded transmission lines feeding from the thermocouple unit located in the antenna system under test. These leads must be thoroughly shielded, by-passed, and provided with radio-frequency choke coils at both ends to prevent radio-frequency pick-up by the meter leads.

9.12. Radio Beacon-signal Methods. a. The Aural System.—Figure 9-24 illustrates the principle of the aural type of radio-range beacon which uses the Morse code letters for identification. The signals transmitted from this system are the Morse letter *N* represented by the code signal $--$ and the letter *A* represented by the code signal $\cdot-$. These two signals are interlocked so that when they are transmitted the first sound heard will be that of the dash in the letter *N* signal, then the dot of the letter *A* signal, followed by the dot of the letter *N* signal and finally the dash of the letter *A* signal.

When the craft is moving in the correct course, or along the "on-course" or "equisignal" zone, the two code signals merge into one long dash to form the letter *T* in the Morse code. In other words, if the craft is within the "on-course" zone, then the double signal will be heard in

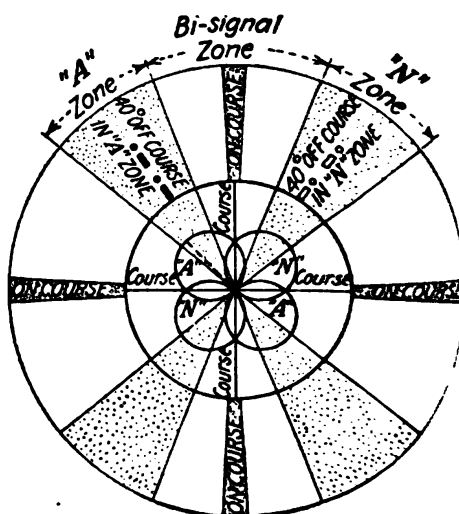


FIG. 9-24.—Aural-range-beacon signal pattern.

the telephones with fairly equal intensity and when the craft moves into the "off-zone" area, one signal will be louder than the other. That is to say, if the craft is in the zone area of the Morse signal N, then that signal will be the only one audible, while, if the craft is in the A-signal area, then that will be the only signal audible. Thus, when both signals are audible, as a long dash, it is a true indication that the correct course is being followed. By maneuvering the craft in one direction or the other when "off course," the "on-course" heading will be reached in which both signals interlock to form the single or long-dash signal T. The zone in which either the N or the A signal predominates is generally referred to as the N or A quadrant, respectively. In order to establish a definite direction of the on- and off-course indications with respect to the true north, the N characteristic has been assigned to the quadrant through which the true north line from the transmitting station passes. If the true north line coincides with the center of a zone in which an equal intensity signal is obtained (the center of an equisignal zone) then the adjacent quadrant on the west is the N quadrant. These conditions are illustrated by Fig. 9-25(a) and (b).

b. *The Visual System.*—In this system the beacon transmitter is modulated to produce two different notes or tones of 65- and $86\frac{2}{3}$ -cycle note corresponding to the A and N signal. In other words, the radio-

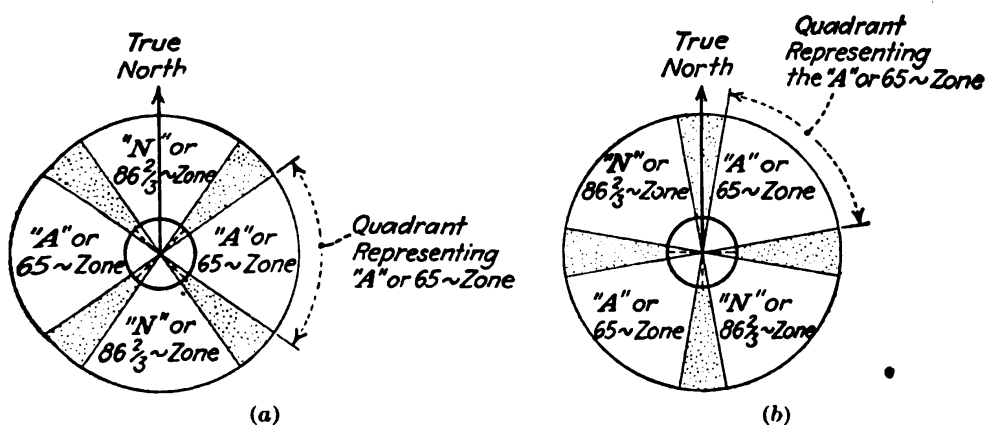


FIG. 9-25.—Radio beacon quadrants.

range quadrants in the visual system are expressed in 65 and $86\frac{2}{3}$ cycles to substitute for the two letters used in the aural-beacon system.

The transmitted signals operate a course indicator composed of vibrating reeds or a pointer type of instrument. In the former, two reeds are used, placed parallel to each other in a small metal case with tips painted white, both being visible through a glass panel. A name plate is provided to indicate the frequency to which each reed is resonant. These reeds are composed of a magnetic material situated close to an electromagnet so that when a signal is passed through the receiver, the modulated component of the radio wave, when rectified by the vacuum-

tube detector, will pass through the electromagnet and cause magnetic variations. Since these variations may be of either 65 or $86\frac{2}{3}$ cycles, or both, depending upon the position of the craft in the beacon course, the reeds will vibrate in direct proportion to the strength of the received signal owing to their mechanical resonance to the electromagnetic variations. In other words, if the craft is off course, either one or the other of these reeds will vibrate depending upon which of the two frequencies is prevalent. If the craft is in the on-course zone, both reeds will vibrate equally. Hence, by noting the amplitude of the rapid vertical vibrations of the reeds, the pilot may determine whether he is approaching the on- or off-course position.

With the pointer type of indicator, which is actuated by a reed converter using a pair of reeds similar to those of the reed indicator, visual indication is provided by a microammeter, the course direction being marked by the position of a pointer on a course or off-course scale. A reversing switch is provided to insure that the deflection of the pointer is in the same direction as the deviation of the craft from its course.

c. Shifts in Radio Beam.—Safety of life often depends on the accuracy of the radio guide beams along established air routes. Studies¹ made indicate that these beams may deviate almost $+1.0$ degree to -0.5 degree from normal in average weather during a year. As much as 10 degrees variation was observed during a severe snowstorm, whereas no comparable deviation occurred during rain. The beam returned to normal with the abatement of the storm.

It seems apparent that rigid accuracy cannot be assumed for all radio guide-beam beacons at any time unless such accuracy is checked by observations both lengthy and continuous.

9.13. Marker Beacons.—These beacons are located at range stations and are divided into three so-called "types." These are (a) zone markers, (b) fan markers, and (c) low-frequency markers.

a. Zone markers emit a cone-shaped field of energy on the ultra high frequency of 75 megacycles, emitting a steady tone of 3,000, 1,300, or 400 cycles. Their function is to make a check against the cone of silence possible.

b. Fan markers emit a fan-shaped field of energy which at its highest practical level may be 15 miles wide and 5 miles deep. This emission is also on 75 megacycles, with the same audio tones as the zone marker. The identification signals for each course, beginning on the true north leg, or in the absence of true north, the first leg of the east of true north, are, going clockwise, single dots and groups of two, three, and four dots

¹ Observations made by Dr. H. T. Stetson of Massachusetts Institute of Technology and reported with deviation curves in *Electronic Industries*, Vol. 2, No. 1, p. 47, January, 1943.

as shown in Fig. 9-26. The function of the fan marker is to provide definite ground "fixes."

c. Low-frequency markers or "squawkers" operate on the same frequency as the range station at which it is located. The transmitter used is usually of 10 watts output, very low power, and thus of very limited range. Their function is to provide a mark for obtaining definite ground "fixes." Low-frequency markers are being replaced by the previously described ultra-high-frequency markers.

9.14. The Single-loop Direction Finder for Aircraft.

a. Description.—Radio direction finders utilizing the conventional rotating loop designed to make them adaptable to aircraft have been developed and are in use on transoceanic aircraft. These outfits require a trained operator for their operation and are not adaptable to general use by itinerant pilots. On the other hand, aircraft flying regular airways use radio-beacon receivers which are not directional in themselves. Until the development of the radio direction finder to be described in this section, the itinerant pilot had no radio aid in his navigation.

The features of this device, which is known as the *single-loop-antenna* radio direction finder to differentiate it from various double-loop-antenna radio direction finders previously used with unsatisfactory results, may be enumerated as follows:

1. It gives semiautomatic accurate bilateral indication.
2. It can be added to the standard radio receiver of the aircraft.
3. It gives definite directive courses with no ambiguity.
4. It operates on both modulated and unmodulated radio waves from any source (thus broadcasting stations can be used as beacons).

b. Principle of Operation.—A loop which is not symmetrical to the ground acts partly like a vertical antenna in addition to exhibiting inherent loop characteristics. The result is a modified cardioid characteristic as shown in Fig. 9-27(a) and (b), the dotted lines showing the perfect cardioid without the antenna effect present, the total effect being produced by the phase difference between the loop and antenna-effect currents. Assume further that this characteristic is secured by unbalancing the loop by grounding one end of it, which we shall call end *A*, the ungrounded end being called *B*. It is logical, therefore, that, if now end *B* is grounded instead of end *A*, a characteristic opposite to that shown in *a* will result. This is shown as curve *b* where again the dotted

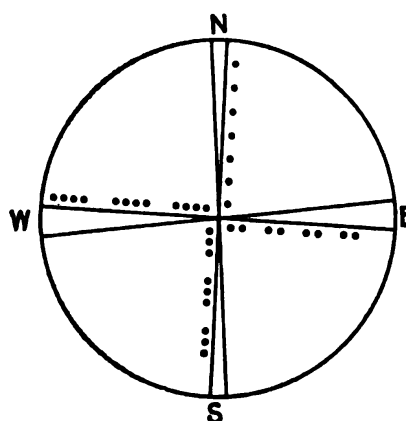


FIG. 9-26.—Identification signals for fan marker beacons.

line shows the perfect cardioid. If a zero-center meter is caused to deflect to the right when the end *A* of the loop is grounded producing curve *a*, and to the left when end *B* is grounded producing curve *b*, and if, furthermore, ends *A* and *B* are grounded alternately in rapid succession, it is obvious that a bilateral indication of the direction of the received signals is available on the meter. It is the function of the direction-finder circuit to provide for this alternate grounding of the loop ends, and the

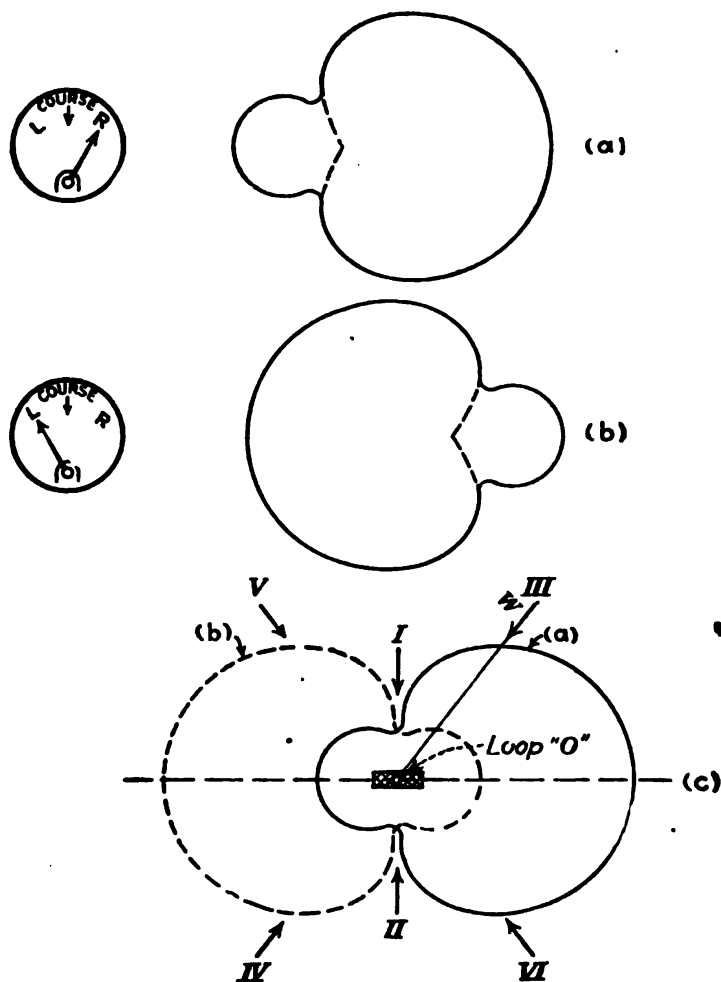


FIG. 9-27.—Characteristics of unsymmetrical loop.

way in which this takes place will be explained in connection with the theory of operation of the entire circuit which is shown in Fig. 9-28.

c. Theoretical Operation of the Direction-finder Unit.—Let us first analyze the operation of the rectifier unit during the period in which no incoming radio-frequency signals are being received. An alternating e.m.f. of an audio frequency is developed by the oscillator circuit and the tube V_1 . These low-frequency oscillations in the primary winding of the transformer T_1 induce an alternating e.m.f. across the secondary winding S of this audio-frequency transformer. During the period in which the e.m.f. across S is such that a positive potential is applied to the plate of the tube V_1 and a negative potential to the plate of the tube V_2 , a current will flow from the cathode of V_1 to the plate, through the radio-frequency choke RFC_1 , through the

winding S to ground, through the secondary winding of the audio-frequency output transformer T_2 , through the portion X of the resistance R_1 , returning to the cathode to complete the circuit. This flow is indicated by the heavy arrows. When the audio-frequency cycle across S of T_1 changes, the positive potential which operates tube V_1 reverses, and the current flows in the direction of the dotted arrows. During each half-cycle, therefore, a current passes through the resistance R_1 , first in one direction and then in the other as the cycle changes. This also results in a current flow through the meter M , first in one direction and then in the other, since it is connected in parallel with the resistance R_1 . However, since the audio-frequency cycle across the resistance and the meter is continually reversing, the current through the meter will be balanced out and the resultant reading will be zero.

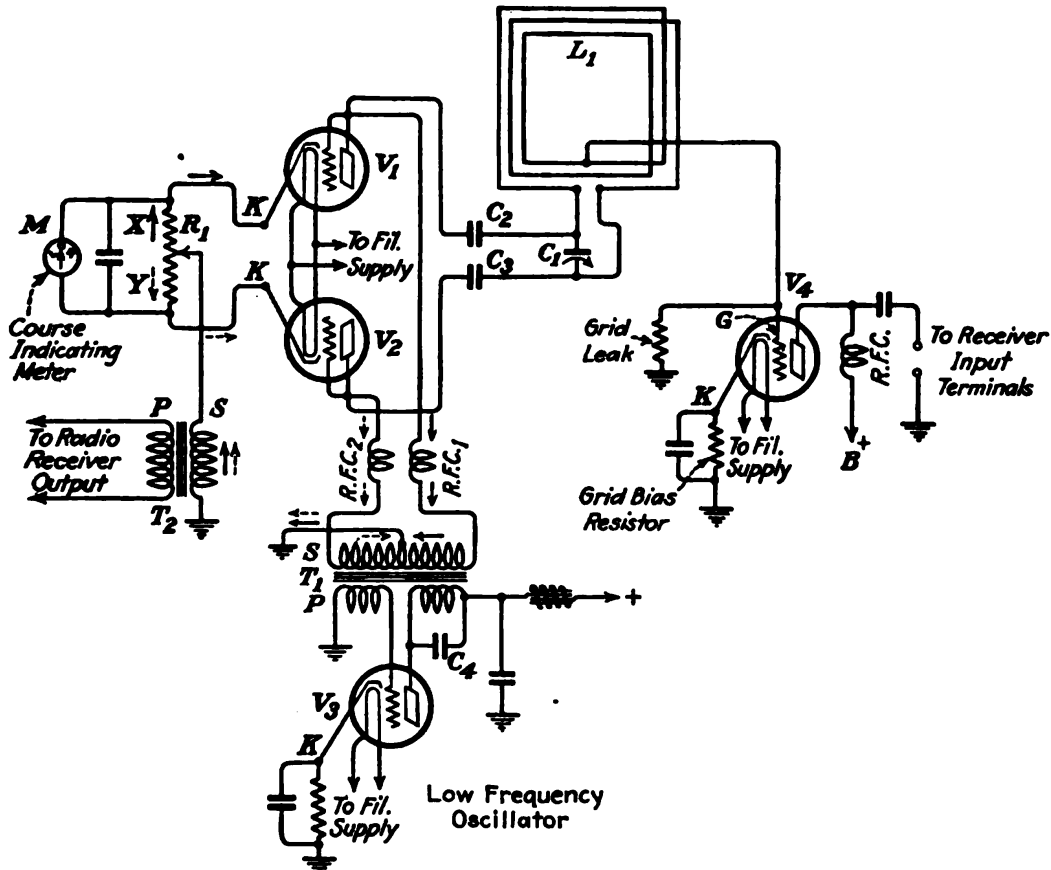


FIG. 9-28.—Circuit diagram of single-loop direction finder for aircraft.

Now, when a radio-frequency signal e.m.f. is developed across the tuned circuit L_1C_1 , these voltages are applied to the grid and cathode terminals G and K of the radio-frequency amplifier tube V_4 which results in radio-frequency variations in its plate circuit and through the primary winding of the radio receiver. These radio-frequency signal variations are then amplified through the regular receiver in the general manner, with the exception that, instead of feeding the output signal into an audible indicating device such as a head telephone receiver, the signals are fed back into the special direction-finder unit through the medium of an output transformer T_2 . This results in amplified signal voltages being developed across the secondary winding S of T_2 . Now, with this signal present across this winding, let us see what the effect will be when both the audio-oscillator and the signal voltages are combined.

When one of the rectifier tubes V_1 or V_2 receives a positive potential from the audio-frequency oscillator its plate-to-cathode conductivity is quite high, which

results in effectively grounding one end of the loop antenna through the secondary of T_1 . In other words, the loop is effectively grounded at the end in which the positive potential is applied to the rectifier-tube plate. Similarly, when the audio-frequency potential reverses to the other tube, then the loop is effectively grounded at the other end. Two field patterns are thus alternately produced at an audio frequency as illustrated in Fig. 9-27(c). Owing to the antenna effect introduced by the rectifiers, these field patterns take the form of a modified cardioid characteristic of a broad or periodic nature.

Thus, when the tube V_1 is functioning, the current passing through the loop produces one field pattern while, when the other tube V_2 is functioning, the other pattern is produced, forming a typical figure-of-eight characteristic. Assume V_1 is operating, then, when the incoming-signal voltages are induced across the loop and amplified through the regular receiver and across the secondary winding of T_1 , the signal will be proportional to the field pattern at that moment, owing to the fact that the loop antenna is effectively grounded at one end. Consequently, the current passing through the meter indicator M will be proportional to the combined e.m.f.s. of the oscillator and signal voltages. Now, when the rectifier cycle reverses and V_2 operates, then the other end of the loop antenna will be effectively grounded and the current through the indicator M will pass in the opposite direction. Since the cycle is continually reversing at the frequency of the audio oscillator, the two e.m.f.s. are alternately applied to the indicator M . It may thus be readily seen that the currents tending to deflect the indicator to the right or left must be directly proportional to the difference between the signals due to each pattern. If the pointer of the meter, therefore, is fixed at the center of the scale, the heading of the craft to the right or left may be readily determined. A variation of 10 degrees from the line of flight will produce practically a full-scale deflection to the right or left with an average adjustment of volume on the receiver.

d. Sense Effect.—Signals arriving from points I and II in Fig. 9-27(c) give an on-course indication on the meter. Now, if a signal comes from point III, the current through the meter will be the sum of the current produced by the curves a and b or OW . Also, as OW lies to the right of the on-course line I-II, the meter will deflect to the right, and the loop must be rotated toward the right for an on-course indication. Likewise, if the signal arrives from the direction V , the meter will read to the left of the on-course reading. Therefore, when heading toward the source of signal, the meter deflection indicates the direction the loop must be turned for an on-course reading, and a directive sense effect is secured.

e. Construction and Performance.—This direction finder is made up as a complete unit which may be placed near the standard radio receiver to which it is attached. It has a single-control knob which varies the loop-tuning condenser C_1 . The standard radio receiver must also be tuned to the desired signal, but this is not difficult as all other signals are absent owing to the preselection characteristics of the radio-frequency amplifier in the direction-finder unit.

During operation a constant tone of low intensity is present when flying on course. If off-course indications are received, this tone becomes louder thus giving an audible check on the course indication.

The small loop used with this unit is located outside the fuselage immediately over the instrument location or as close thereto as possible.

Some error is introduced by aircraft structure, but this is usually very slight and the accuracy of this direction finder was found on test to be of the order of 1 degree.

Signal intensity is controlled by the volume control in the standard receiver.

The original models of this direction finder utilized a fixed loop. Hence, this compass was used mainly as a "homing" device. More recent models employ a loop which may be rotated, thus permitting the taking of bearings on stations not in the direct course line.

NOTE.—For information on aircraft-radio direction-finders design for maritime service see Secs. 16.7, 16.8*d*, and 16.11.

9.15. The Sperry Automatic Radio Direction Finder. *a. General Description.*—The equipment consists of a control and indicating unit, a sense antenna, receiver, and a streamlined housing in which is mounted a pair of shielded loops. The control unit is arranged to furnish the pilot with continuous bearings throughout 360 degrees. These bearings are indicated by a pointer moving in the horizontal plane over a 360-degree scale. The pointer is connected by flexible shaft to the loop assembly, which is fitted with a motor controlled by the receiver output. The action of the motor-control circuits brings the loop to a null on the station to which the receiver is tuned, and this null is continuously and automatically maintained, without 180-degree ambiguity, irrespective of changes in the heading of the airplane.

A number of desirable features, hitherto unavailable, are incorporated in this direction finder. It supplies continuous and automatic non-ambiguous bearing indication and simultaneous headphone reception in the 200 to 500-kilocycle and 550 to 1,500-kilocycle bands. Its visual indications are given naturally, on a horizontal dial, and navigation scales are provided so that relative, magnetic, or true bearings may be read without reference to tables and without the necessity for mental calculations. Accurate cross bearings can be obtained almost as quickly as the various stations can be tuned.

Means have been provided for operation of the automatic direction finder under precipitation static conditions, where the use of an unshielded sense antenna would be impossible.

When the direction finder is operated under precipitation static conditions, the sense antenna may be disconnected and a second shielded loop substituted for it by means of a switch on the control unit. Automatic operation is provided as before, except that a line of bearing is given instead of the single-direction non-ambiguous bearing furnished when the sense antenna is connected. The second loop, used to replace



FIG. 9-29.—Sperry automatic radio direction finder installed in plane. (Courtesy of Sperry Gyroscope Co., Inc.)

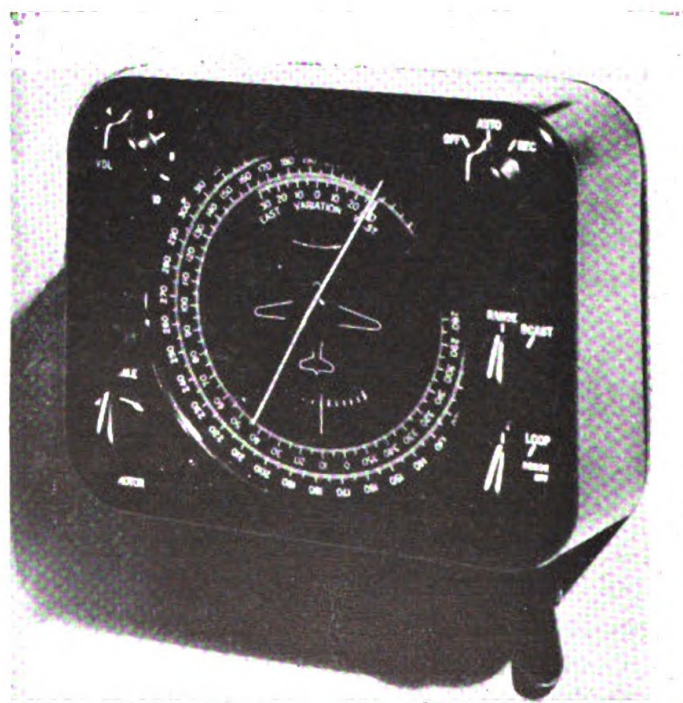


FIG. 9-30.—Sperry automatic D/F single control unit. (Courtesy of Sperry Gyroscope Co., Inc.)

the sense antenna, is mounted in the streamlined housing on the same shaft with the null loop, but displaced from it by an angle of 90 degrees. As a result of this arrangement, continuous headphone signal is provided by the second loop, which is maintained at the position of maximum pickup relative to the reference station.

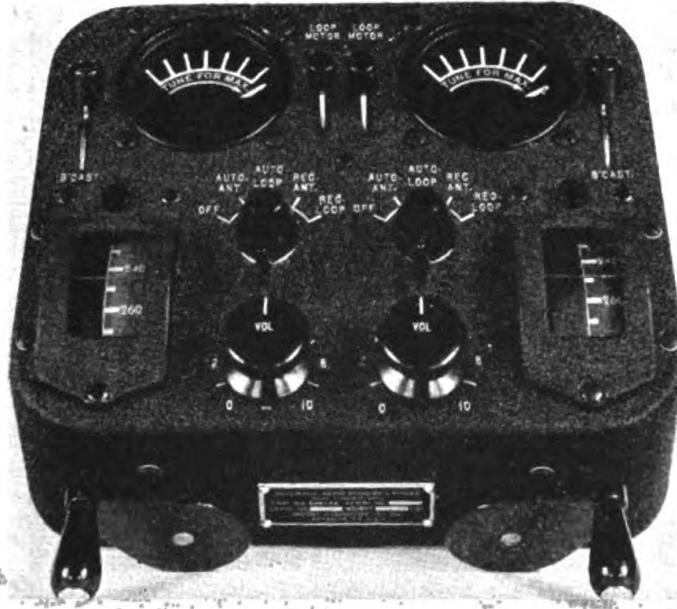


FIG. 9-31.—Sperry automatic D/F dual control unit. (Courtesy of Sperry Gyroscope Co.)

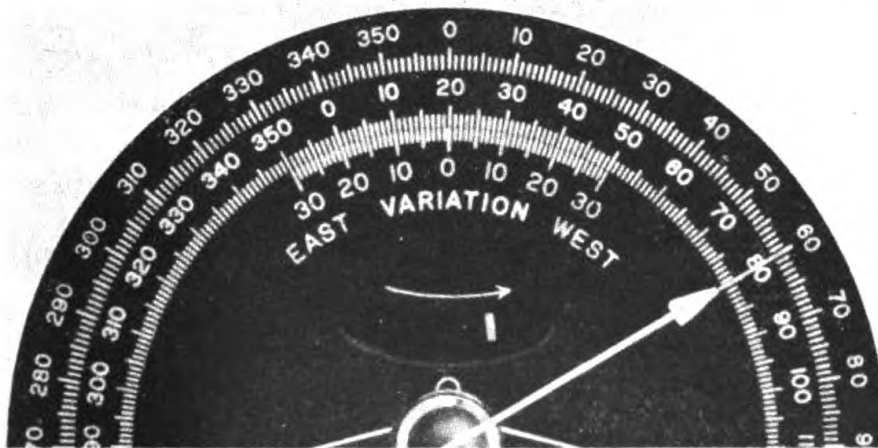


FIG. 9-32. —Navigation scale. (Courtesy of Sperry Gyroscope Co., Inc.)

The control unit and indicator is designed (see Fig. 9-29) to mount on the throttle column where it may be operated and observed conveniently by both pilots. The single unit is shown in Fig. 9-30, and the dual unit is shown in Fig. 9-31.

Navigation scales are provided to permit ready determination of relative, magnetic, or true bearings without the necessity for calcula-

tion. The use of these scales in typical problems is shown in Figs. 9-32 and 9-33.

Quadrantal error is automatically compensated by a cam mechanism in the base of the control unit, provision being made for easy insertion of the correct cam at the time of installation.

Study of aircraft-radio-equipment layouts indicates that in certain cases it may be expedient and economical in weight and cost to use the automatic direction finder as a replacement for the range receiver. Under these conditions, the auxiliary receiver would normally be used as a range receiver, with the automatic direction finder continuously in use as a homing or drift indicator when tuned to the range station next ahead.

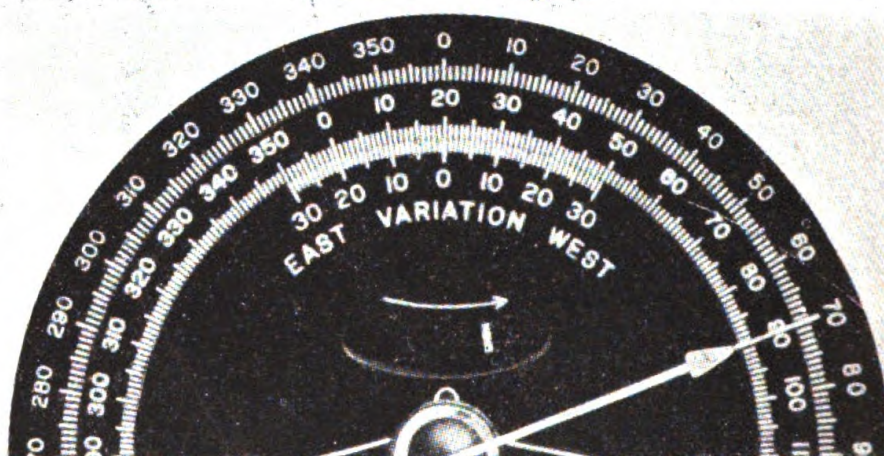


FIG. 9-33.—Navigation scale. (Courtesy of Sperry Gyroscope Co., Inc.)

The gross weight of the equipment when installed, including flexible shafts and wiring, is approximately 75 lb. However, as indicated, if the receiver replaces certain existing equipment, the net increase in weight is considerably less than this amount.

The power required is 8.5 amp., 12 volts when in full automatic operation.

b. Detailed Description.—The control unit and indicator combines in a single centralized location all the controls, indications, and navigation scales that are used in the operation of the equipment.

The azimuth-indicating pointer on the control-unit dial has a maximum speed of 30 degrees per second in turning to the desired stations and comes to rest on the correct bearing without overshoot or hunting. Successive bearings on strong signals in the absence of noise are reproduced to within 1 degree.

Flexible shafts carry the tuning drive from the control unit to the receiver and the pointer drive from the loop assembly to the control unit. The drive shaft from the loop to the pointer serves a dual function: in automatic direction-finder operation this shaft is driven by the loop motor at a ratio of 36:1 to the loop, but during manual aural-null operation the loop is oriented through this same shaft, driven by the tuning crank on the control unit, which is clutched in to engage the loop drive mechanism.

In addition to this arrangement for manual orientation, the LOOP MOTOR switch provides a motor drive for rapid right or left orientation of the loop. This reversing switch can operate the loop drive motor only when the selector switch is in the REC position and, therefore, cannot interfere with automatic radio direction finding.

A tuning meter is provided to assist in precise tuning.

A cam arrangement for the automatic correction of quadrantal errors is built into the base of the control unit. This cam may be cut to shape easily to correct for errors introduced by the structure.

Illumination is indirect and is controlled by a dimmer control knob on the underside of the control unit where it is out of sight but readily accessible. Lamps may be replaced without removing the control-unit cover.

c. Receiver.—The combined receiver and power supply are especially designed for use in this equipment. All the details of design and construction have received painstaking care to insure trouble-free operation and easy servicing. For example, radio-frequency coil assemblies are in unit form, including coils, trimmers, and band-switch sections. Special attention has been given to sensitivity, selectivity, and image attenuation. The selectivity is such that bearings can be taken on range stations separated by only 3 kilocycles, with audio fidelity adequate for intelligibility.

The receiver and power supply are in one unit which fits in a full-depth rack section. Receiver and power-unit assemblies are available for 12- and 24-volt direct-current operation. A motor-driven function selector and band-change switch is provided and controlled by switch knobs on the control unit. The ratio of the tuning shaft to the condenser shaft is 264:1. All cable connections to the receiver enter through fittings on the front panel. Where the receiver is not rack mounted, a shock-mounted base plate is available, from which the receiver may be readily detached.

d. Loop and Drive Mechanism.—The loop-antenna system consists of a molded Bakelite streamlined housing in which is rotatably mounted a pair of shielded crossed loops. A motor at the base of the loop-support casting is geared to the loop shaft at a ratio to provide a maximum loop searching speed of 30 degrees per second. Special attention has been given to the design of this motor to insure a minimum of maintenance in service. It is a two-phase alternating-current motor containing no slip rings or brushes; thus a common source of maintenance trouble is eliminated. The loop cable is at medium impedance, giving good gain combined with reasonably permissible cable length.

The dual loop assembly contains the null loop (outer) and the sense loop (inner). The null loop is used for all direction-finder indications. The sense loop is used in addition only for antistatic automatic operation to furnish the reference radio-frequency signal and audio headphone signal normally supplied by the sense antenna.

The complete loop and motor-drive assembly can be detached from the airplane by removing the attaching bolts from the outside. If a

hand hole is provided in the skin of the ship for the purpose of reaching the cable and shaft connections, the loop and motor-drive assembly may be quickly and easily replaced without entering the airplane.

e. Advantages.—The automatic direction finder may be used with equal facility for homing or for taking cross bearings for ascertaining the position of the airplane. It does for the navigator what the gyropilot

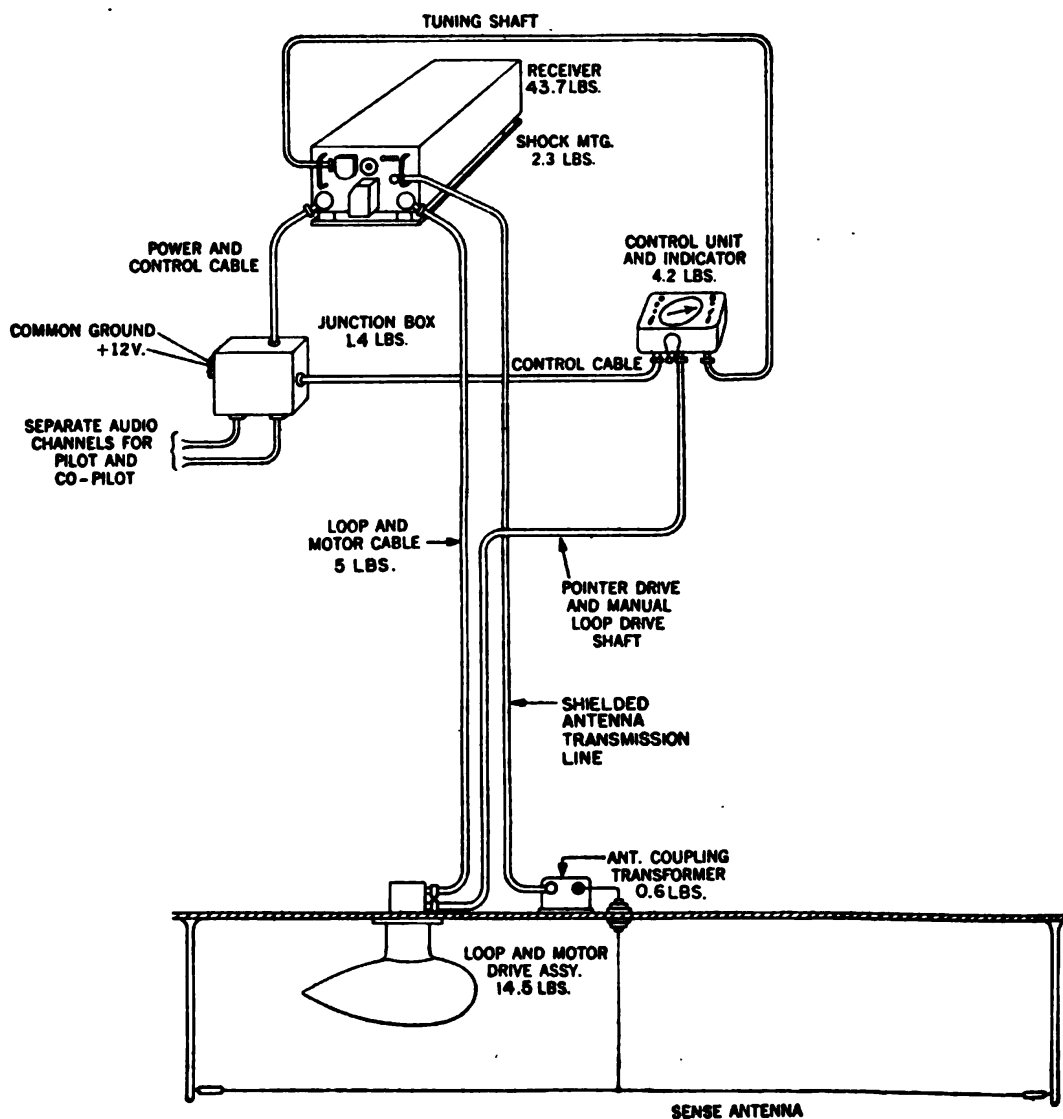


FIG. 9-34.—Sperry automatic D/F equipment arrangement. (Courtesy of Sperry Gyroscope Co., Inc.)

does for the human pilot, that is, it reduces the number of duties he has to perform, thereby permitting him merely to supervise a series of operations rather than have to perform the operations himself.

Its greatest advantage, of course, lies in the fact that once tuned to a station it continues to indicate the direction of that station, irrespective of the heading of the airplane over the ground, whereas the loop of the ordinary radio compass must be manually adjusted to the null position

whenever it is desired to take a bearing. The continuous, automatic, non-ambiguous bearing is a tremendous aid in solving the orientation problems. The pilot sees at a glance the relative and magnetic bearings of the range station throughout the problem, and quadrant identification becomes a simple matter.

The automatic radio direction finder checks the cone of silence unmistakably, the pointer swinging around 180 degrees and pointing in the opposite direction in the time it takes for the airplane to cross the cone of silence.

An exclusive feature of this equipment is the dual loop arrangement which provides automatic operation under precipitation static conditions which make it necessary to abandon use of the sense antenna. In these difficult conditions, the pilot still has the convenience of automatic operation to which he has become accustomed, except that now line bearings are given. There is no necessity for reverting to manual loop rotation.

The Thyatron control circuit provides smooth and dependable motor performance, as distinguished from tube or relay devices of the off-on type, and incorporates a positive antihunt system, which permits rapid loop and pointer movement without hunting or error.

The equipment is easily installed in any airplane. As shown in Fig. 9-34, there are only three items of equipment in addition to the antenna transformer and junction box. The receiver assembly with built-in power supply and automatic-loop motor control reduces to a minimum the number of cables. The loop cable is furnished completely assembled and ready for use.

CHAPTER 10

BROADCAST STUDIO

Any study of broadcasting must consider the subject of acoustics and sound control as these are the first factors affecting the broadcast program.

I. STUDIO ACOUSTICS

10.1. Distortion.—The never-ending problem of the radio studio is distortion. The importance of this matter is evident because no amplifying apparatus, even though it may be almost perfect in design, can give faithful reproduction if the sound impressed upon its input is distorted. And this may take place in many ways. There are two ways in which the microphone itself may be the cause of distortion. One of these is by distortion of the wave front, consisting of a series of condensations and rarefactions in the air, or more simply, variations in air pressure, due to the shape and bulkiness of the microphone itself.

Such distortion is similar to the change caused in the form of a water wave when it hits a large immovable object such as a pier. If the immovable object is comparatively small and offers little resistance, such as the edge of a knife blade, the true form of the wave at that point in space is very little altered. Similarly, if it is desired to keep a microphone from altering the audio-frequency wave form striking its active surface, every effort should be made to approximate as nearly as possible the same relation between it and the sound wave as was present between the knife blade and the water wave. This condition becomes more difficult to fulfill as the audio frequency is increased and the wave becomes correspondingly smaller.

The particular type of distortion caused by the microphone cannot ordinarily be corrected when the microphone is in use. It is necessary, therefore, so far as possible, to take care of this in the original design of the microphone. Controlling factors are the size and shape of the microphone, which should be kept as small as possible and be streamlined to sound. In other words, an effort should be made to achieve acoustical transparency.

Another cause of distortion at the microphone is acoustical resonance. This results from the cavity formed by the diaphragm and the walls of its retaining ring. Every effort is made to eliminate this cavity resonance in the design of microphones.

10.2. Reverberation. *a. The Terms "Live" and "Dead."*—These terms enter frequently into any discussion of acoustics. If it is said that a room is dead, it is meant that there is little or no reflection of a sound wave from the walls of that room. This term may refer to only a particular section of a room, that is, a room may be only partly dead. An example of a truly dead position would be a location in interstellar space where any sound originating from a point would never return to it in the form of a reflected wave.

On the other hand, in a live room, a great deal of reflection takes place, and the sound may return to its source many times before it finally dies away. An example of a live room is one having highly reflecting tile walls. This term also may refer to only a part of a given room. Thus there are gradations between a very live room and a very dead room, depending on the *reverberation* characteristics of the room, that is, upon its ability to reflect sound waves

b. Reverberation time is an expression of unit reverberation and is defined as follows: Assume a sound source to produce a sound intensity (energy) at a given point in a room of one million times the energy which would be just audible; if this source be stopped, the reverberation time is the time taken for the sound energy at that point to fall to a just audible value.

A formula, known as *Sabine's formula*, which is sufficiently accurate for most rooms, is expressed

$$t = \frac{0.05V}{as} \quad (1)$$

where t = reverberation time in seconds.

V = volume of room in cubic feet.

a = average coefficient of absorption of these surfaces.

s = total area of absorbing surfaces in square feet.

It is thus seen what factors enter into making a room live or dead.

A microphone placed in an almost dead studio, that is, one having walls capable of a high degree of sound absorption (short reverberation time) will pick up the required sound only once, that being directly from its source. Contrary to what might be expected, the effect of this is usually displeasing. We are accustomed to a certain amount of reverberation, and, if this amount is not present, the sound affects us as being flat, shallow, and uninteresting. For the same reason it is very irksome to the artist to work under these conditions.

c. The Absorption Coefficient.—There is an ideal time lag (reverberation time) and volume proportion between the original and reflected sound striking the microphone. If this is achieved the resultant sound will be natural in quality, neither too dead nor too live.

The quantity relation between the original and reflected sound depends, among other things, upon the efficiency of the reflecting surface. Different materials possess reflecting properties in varying degrees, dependent upon their structure and surface. In a treatise on acoustics it is more usual to speak of the absorption coefficient of a material than

its reflecting efficiency. The *absorption coefficients* for a variety of materials have been measured at the U.S. Bureau of Standards, and the results, at frequencies from 128 to 4,096 cycles, are available upon request.

The value of the absorption coefficient becomes higher as the frequency of the sound wave increases. The ideal number of fixed absorption units present in a studio depends upon a number of things, the most important being the cubic content of the room, the number of performers present, and the instruments involved.

10.3. Standard Practice Broadcast Studios.—Standard studios are treated to give the exactly desired reverberation time. This is in all cases different from the reverberation time that would be taken as ideal for a concert hall or for direct listening to music. Because of the binaural effect, that is, because we listen with *two* ears, we are able to localize the source of a sound to a greater extent. In other words, we have an aural sense of direction. This is due to the difference in time of arrival of a sound to one ear from its time of arrival at the other. Hence, when listening directly to a symphony orchestra we may sense, with our eyes closed, that the tympany section is to our right and the bass fiddles to our left.

When listening to a broadcast of the same sounds originating from a point source, such as offered by a speaker, this directional sense disappears concerning individual instruments, and we get a condition similar to that which would obtain if we had listened to the original sound with one ear. If you try the experiment, you will find that the loss of directional sense entailed by listening with one ear increases the apparent reverberation to a great extent. To make up for this apparent increase, broadcast studios are normally treated to have a shorter reverberation period than would be desirable for direct listening. This tends to make the studio itself sound "dead" to the performers.

The proper reverberation period of a given studio is first calculated by formula, and the studio is then treated with sound-absorbing materials to give the desired reverberation time. These materials are placed about the walls in plaques. There are a number of materials on the market which are specially designed for this use and which have different absorption coefficients at different frequencies. It is a relatively easy matter to obtain the desired absorption coefficients at the higher frequencies by the use of the proper amount and combination of these materials. Absorption of the high-frequency sounds is due mainly to the surface characteristics of the materials involved in relation to the wave length of the sound.

At the lower frequencies, which have a long wave length, the surface characteristics become more and more unimportant and it becomes increasingly difficult to get absorption. These frequencies also carry the bulk of the acoustical power in the sound wave.

Studios are treated for absorption of the lower audio frequency by setting up the treating materials in the form of a panel which is free to move with a diaphragm action. The lower frequencies impinging on these panels actually move them back and forth, their energy being absorbed in the process. Thus there is less left to be reflected. Such panels make it possible to construct studios that will have any desired reverberation-versus-frequency curve that is desired and is within reason.

In designing a studio, it is necessary to keep in mind that any reflection paths must be broken up in order that standing waves shall not be produced. To illustrate: If there were two non-absorbing surfaces parallel to each other, such as the ceiling and the floor of the room, a sound wave originating between them would travel to the ceiling and bounce back again to the floor, then back again to the ceiling with practically the same energy, then back again to the floor, and so on. As both surfaces are highly reflecting, very little energy is absorbed and the sound will continue to bounce back and forth. Hence, a semisteady state or condition will exist, with a very slow decay of sound as the wave energy becomes exhausted. Now if this region between the floor and the ceiling is explored by a microphone, it will be seen that the sound intensity increases and decreases from a very small value to a very large value at different points between the floor and ceiling. This is due to the fact that the waves bouncing back and forth between the floor and ceiling at some points add their effects and at some points neutralize each other.

There are two basic ways of avoiding such a condition. Either a highly absorbent plaque can be placed on the floor or ceiling so that the sound will be rapidly absorbed as it travels back and forth, or the ceiling may be set at a slant so that the sound will not return to the floor over the same path. Thus, it is good practice to set the walls and ceilings of a studio slightly off true and also spread the sound-absorbing plaques at different spots around the whole of the studio rather than concentrate them at one point. These measures will prevent such standing waves of sound from being set up.

In following out this same idea of breaking up standing wave paths, there is a more modern trend of thought in studio design. These studios use very little sound-absorbing materials, but do use a great number of curved surfaces so that any sound is reflected over a great many paths. This avoids the setting up of standing waves but with little absorption of the sound energy.

The effect on reverberation is to enable the use of a long reverberation time without producing echo or cavern effects. The advantage is that the studio sounds very brilliant and gives a fine reproduction of even the highest audio frequencies. Because these studios are so "live," the acoustic levels are high and a non-directional microphone will pick up about the same sound regardless of its position in the studio. This

latter statement is, of course, to be interpreted within reasonable limits. Performers enjoy working in such studios for the same reason that you enjoy singing in a bathroom.

Many experts believe in having a live and dead end in each studio. The microphone is placed at some distance from the performers in the dead end of the studio and is encompassed on three sides by sound-absorbing material. The artists are placed in the live end. This simulates the condition found in the usual concert hall where the platform is live and the ear of the individual in the audience is surrounded by other persons who are acting as sound-absorbing surfaces. It is questionable, however, if the best place to hear music is in a concert hall.

Because it is important to keep unwanted sound out of a studio and to keep the sound in a studio from getting out into another adjoining unit, many studios are "floated." There are a number of systems for accomplishing this result, but they are all variations of one fundamental scheme. The studio is built as a room within a room and is isolated from the walls of the outer room (which constitute the building proper) by means of springs. Thus, the ceiling is hanging on springs, the floor is resting on springs and the walls are attached only to the ceiling and the floor, in so far as this is possible. The spring action prevents vibrations from being transmitted from the studio to the building, and vice versa. In order to be effective, there must not be a solid tie between the outside and inside wall, and needless to say the spring tension and studio weight must be calculated so that the resonant frequency of the system falls outside the range of frequencies under consideration. Also all electric cables, air-conditioning ducts, and other similar installations between the two walls must be of a flexible or non-sound-transmitting nature. As such soundproof studios must of course be hermetically sealed, air conditioning of some sort is an absolute necessity. In order to prevent sound from one studio reaching another via the air-conditioning system, the ducts must be heavily lined with sound-absorbing material and must be of sufficient length so that all objectionable sound is dissipated before reaching another studio or before loud outside sounds can be introduced into the studios.

10.4. Production and Microphone Placement.—The effective acoustics of any particular studio are very much influenced by the type of microphone used and its placement. This is apparent after a moment's thought. If a non-directional microphone is used, it receives reverberated sound from all points of the room. If a bidirectional microphone is used, half the reverberation is not received. If a unidirectional microphone is used, reverberation is not received from three sides. If a beam microphone is used, the reverberation is still less.

It is at once apparent then that a simple way of instantly changing effective studio acoustics is by using microphones having different directional characteristics. The use of such different microphones has to a

large extent replaced the older method of adjusting studio acoustics by the introduction of more or less absorbing or reflecting material in the form of screens placed at strategic points in the studio.

With any given microphone, the effective acoustics of a studio are very materially changed by the distance relationship between the performer and the microphone. This would not be true in a completely dead place such as a point 5 miles up in the earth's atmosphere where there would not be much chance of reflected sound returning to the microphone. However, it would be very true in such a place as a tile bathroom where the volume of reflected sound hitting the microphone could easily exceed the value of the original sound, owing to the formation of standing waves. In the light of the above, it may be seen that the time lag between the original and reflected sounds at the microphone is not important if the sounds are not comparable in intensity. If they are comparable, it is best to keep the lag short. This may sometimes be accomplished by adjustment of the distance between the microphone and the reflecting surface. In practice, if the conditions surrounding the sound source and microphone are too live and the time lag is very short, the effect produced makes the reproduction sound mechanical and tinny. If, under the same conditions, the time lag is rather long, hollow and cavern-like effects are secured.

The sound relation is very important, and it is usually the easiest to correct. In situations where acoustic conditions already existing must be met, such as in certain broadcasts remote from the studio, satisfactory reproduction can usually be secured if the following operations are carried out. The microphone should be placed as far as possible from any highly reflecting surface. As sound radiates from a given point, its intensity decreases as the square of the distance from the source. Thus, by increasing the distance between the sound source and the reflector, we achieve a decrease in the value of the reflected sound returned to the microphone. Another most important factor in the fight for good reproduction is the possibility of adjustment of the distance between the microphone and sound source. The volume relation between original and reflected sound, and hence the resultant characteristic of the microphone output, may most easily be influenced by experimentation with this distance. Decreasing the distance increases the proportion of original sound, and vice versa. Many times, proper microphone placement affords the only solution to the problem offered by poor acoustics.

It has been stated that the absorption coefficient differs with the material under consideration; also that it increases with the frequency of the sound wave. Thus, if a studio is treated by applying sound-absorbing material to its walls, so that it is ideal for the rendition of a piccolo solo, which consists mainly of high audio frequencies, it may prove hopelessly inadequate for the proper reproduction of a duet between tympani and double bass. Also we may find that the studio which was ideal for a piccolo solo is unsuited to a band of 50 piccolos, as the added absorption of 49 more people and their effect in breaking up the reflected sound waves may deaden the studio to too great an extent.

The adjusting of studio acoustics and the setting up of the artists in broadcasting studios has become a highly specialized field which is taken care of by experts who are known as *production men*. The basic

methods of adjusting studio acoustics to meet varying conditions have been brought out in the above paragraphs.

To summarize then, the effective acoustics can be quickly changed by one of the following methods:

1. By choosing the most desirable directional characteristics for the microphone used.
2. By varying the distance between the performer and the microphone.
3. By varying the effective reverberation period of the studio in respect to the microphone by the introduction of screens of absorbent or reflecting material.

Even with these aids, compromises must be made in setting up artists before the microphone. For instance, the absorption coefficient of the particular studio involved may be very low at the low frequencies set up by a double bass. Owing to this fact, a greater degree of reflection will take place for this instrument than that for others of higher pitch. To prevent improper relation between the original and reflected sounds, the bass is placed closer to the microphone than other instruments of a higher frequency output. This makes the sound energy received at the microphone from this instrument proportionately large and in order to secure musical balance makes necessary the reinforcing of the high end of the audio spectrum by the addition of a greater number of the higher pitched instruments. Thus, the normal concert proportions and arrangements of the instrumental sections of an orchestra are not necessarily normal to broadcasting.

Let us suppose that by means of careful design a "perfect" studio has been achieved. It is desired to broadcast a playlet having three characters, and for the sake of convenience each player is given an individual microphone. These microphones are placed fairly close together, and their outputs are fed into an amplifying system. It may be found that this studio, which gave perfect reproduction when used with a single microphone, has now developed a cavernous echo. This is not due to the studio acoustics, but to the fact that the sound intended only for microphone 1 is also reaching microphones 2 and 3 at slightly different time intervals and volumes. The effect on the resultant output is similar to that which we should have if using one microphone in highly reflecting surroundings. Because of this multi-pickup effect, it is an excellent working rule always to use as few microphones as possible.

Inasmuch as microphones may at odd times be placed in close proximity to each other, it is important that the phase relations of their output be the same. Otherwise their outputs may tend to cancel. If any two microphones each had an identical frequency response, this cancellation effect would simply give a decreased amount of output without affecting quality. However, in actual practice the cancellation is fairly complete for the middle and lower range of frequencies and fairly incomplete at the higher range of frequencies. Therefore, if the outputs

of two microphones in close proximity buck each other, about all that will get through will be some very high-pitched "tinny" sounds that are impossible to use. Thus, it is important in a studio that all microphone outputs be kept in the same polarity.

An effect closely approaching binaural hearing can be achieved when using a point source for the reproduction of sound, by setting up a number of microphones, one for each section of the orchestra to be broadcast or one for each character in a play to be broadcast. If all these microphones were on at once, there would be a multi-pickup effect which would normally be objectionable. However, if with the aid of an extremely competent operator, only one microphone at a time is thrown into the circuit, and that microphone is broadcasting the orchestra section or character important at the moment, a new realism is added to the broadcast sound because it has apparently acquired a directional effect. This technique is sparingly used today because of the skill of manipulation it requires, but its results are highly worth while.

The acoustical properties displayed by different types of microphones will be taken up in conjunction with their electrical properties at a later point in this chapter.

10.5. Sound is divided roughly into two parts, namely, tone sensation and noise sensation. Tone may be graphically represented by a simple sinusoidal curve, while noise is irregular in character. A tuning fork gives the best example of a simple tone. Ordinary music is very complicated in character and consists of a simultaneous sounding of many simple tones together with complex noise waves. For example, the music emitted by a single violin string may consist of as many as six simple tones plus the noise of the bow scraping the string.

The audible spectrum describing the limits of human hearing is shown in Fig. 10-1. This graphical analysis of sound is well worth careful study.

10.6. Use of Logarithms.—By the use of the following information the student not instructed in the use of logarithms may, with some little coaching, be able to handle the decibel computations which appear in the following section.

The common logarithm (abbr. log) of any number is that power to which the number 10 must be raised in order to equal the given number. Hence it is necessary to raise 10 to the second power, or "square" it (10^2), to get 100; therefore, the log of 100 is 2. The log of 1,000 is 3, as we must cube 10 (10^3) to get 1,000. From this it follows that the log of any number between 100 and 1,000 must be 2 plus a decimal. For example, the log of 280. is 2.447158. The 2 is called the *characteristic* and the decimal .447158, the *mantissa*.

The characteristic of any number is *one less* than the number of digits to the left of the decimal point. If the number is less than 1, the characteristic is *negative* and *one greater* than the number of zeros between the decimal point and the first significant number. However, as negative characteristics can be avoided by a method to be suggested later, they need not concern the student for the present. The following

the mantissa of the log, must yet be found. It is for this purpose that a book of logarithmic tables is needed. A logarithmic table is a table of mantissas, as the characteristic is found without a table. Thus the mantissa of a number is found in the table of logarithms, in accordance with directions accompanying the book of tables. The following rule must always be remembered in dealing with logarithms: *The mantissa is always a positive number.*

A very incomplete tabulation of mantissas is given below so that the student may make a rough check on the pad formulas to be taken up later.

Significant Digit	Mantissa
2.....	.3
3.....	.477
4.....	.60
5.....	.7
6.....	.78
7.....	.845
8.....	.903
9.....	.954
12.....	.08
14.....	.146
15.....	.176
18.....	.255

The antilog of any logarithm is simply the number from which the logarithm was derived. It can be found by working backward, or by a table of antilogs. The mantissa gives the number, and the characteristic places the decimal point. For instance, we wish to find the antilog of the logarithm 3.176. By looking up the mantissa (.176) we find that this comes opposite the number 15 in the above table. This gives us the significant figures of the number, but we must place the decimal point by inspection. As the characteristic is 3, we know that the number must have four integers to the left of the decimal point. Hence it is 1500. The proof is that the log of 1500 is equal to 3.176.

A little practice will give familiarity and assurance. A log table is included in the Appendix.

10.7. The Decibel.—Inasmuch as the ear responds logarithmically to variations in sound intensity, any unit used to compare sound levels must, in order to be practical, vary logarithmically. Such a unit is the *decibel* which is one-tenth (deci) of the international transmission unit known as the *bel*, named in honor of Dr. Alexander Graham Bell, the inventor of the telephone. The abbreviation for decibel is db.

The decibel expresses the logarithmic ratios of powers, voltages, or currents in a transmission system. As such it is very useful in expressing gains in amplifying systems and losses in attenuation networks, and in comparing the electrical output of any piece of equipment with a standard.

A listener with acute hearing powers would become aware of a change in sound intensity of a single sustained note when the level is varied 1 db, but not before. The average person would not notice a change in a radio-program level of less than 3 db.

The decibel is expressed mathematically by the equation

$$\text{db} = 10 \log_{10} \frac{P_2(\text{larger power})}{P_1(\text{smaller power})} \quad (2)$$

By always placing the larger power value on the top of the ratio as the numerator, the result will always be greater than one, and the characteristic of the log of the ratio will always be zero or a greater positive value. Thus the use of complicated negative characteristics is avoided. It is obvious in each problem whether a gain (+) or a loss (−) in decibels results. The negative sign can be inserted before the decibel value if a loss is indicated. This will become apparent as the problems are worked out.

A table showing the relation between power ratio and the decibel, and voltage or current ratio and the decibel, is given below. If the proper ratio is known, it is possible, by referring to this table, to ascertain the exact or approximate result in decibels. Likewise, if the decibel value is known the exact or approximate required power, current, or voltage ratio may be found.

TABLE XA.—RELATIONSHIP OF RATIOS TO DECIBELS	
Power Ratio	Transmission Units in Decibels (db)
1 (= 10 ⁰)	0 (= 10 log ₁₀ 1)
1.259 (= 10 ^{0.1})	1 (= 10 log ₁₀ 1.259)
10 (= 10 ¹)	10 (= 10 log ₁₀ 10)
100 (= 10 ²)	20 (= 10 log ₁₀ 100)
1,000 (= 10 ³)	30 (= 10 log ₁₀ 1,000)
Voltage or Current Ratio	Transmission Units in Decibels (db)
0.001	−60.00
0.005	−46.02
0.01	−40.00
0.05	−26.02
0.1	−20.00
0.2	−13.98
0.5	−6.02
1.0	0.00
1.5	3.52
2	6.02
5	13.98
10	20.00
20	26.02
50	33.98
100	40.00
500	53.98
1,000	60.00

Note: In the practical notations which follow, log₁₀ is simply written as *log*, as only logs to the base of 10 are used in this text.

Example 1: It is desired to increase the distortionless volume of a radio receiver. The output tube in use is a 45 type supplying a maximum power to the loud-speaker of 1,600 mw. Consideration is being given to changing this 45 tube to a type 50 tube which has an output of 4,600 mw., almost a 2.9 times increase in power. Anyone

inexperienced in the use of the decibel would most likely consider an almost threefold increase in sound level to result from such a change of tubes. This however is not true, as can easily be shown:

$$\text{db} = 10 \log \frac{P_2}{P_1} = 10 \log \frac{46}{16} = 10 \log 2.87$$

$$\log 2.87 = 0.46; \quad 10 \times 0.46 = 4.6$$

Therefore,

$$\text{Gain} = 4.6 \text{ db}$$

Such a change would only be noticeable by direct comparison with the previous power level and would not be sufficiently great enough to warrant the expense involved.

Example 2: If the type 50 tube in the preceding example is not satisfactory, what power increase would be necessary to effect a noticeable increase in sound level? A change of power to give a gain of 15 db might be tried. Let X represent the new power. The change is to be made from the 1,600 mw. supplied by the 45 tube.

$$\text{db} = 10 \log \frac{P_2}{P_1} = 10 \log \frac{X}{1,600}$$

Therefore,

$$15 = 10 \log \frac{X}{1,600} \therefore 1.5 = \log \frac{X}{1,600}, \quad \text{antilog } 1.5 = 31.6$$

Therefore,

$$\frac{X}{1,600} = 31.6 \quad \text{and} \quad X = 1,600 \times 31.6 = 50,560 \text{ mw.}$$

Ans.

$$X = 50.5 \text{ watts}$$

Such a large increase in power would necessitate the use of a powerful push-pull amplifier which would be rather costly.

Example 3: The necessity of handling large computations in multiplication and division is avoided when the gain in an amplifying system is figured directly in decibels.

It is desired to compute the power levels in a system consisting of a dynamic microphone with an output of -90 db (reference level 0.006 watt) which is working into a preamplifier with a gain of 43 db. This preamplifier is connected to a mixer with an insertion loss of -12 db and is followed by a main amplifier with a 67-db gain. This final main amplifier supplies power to a loud-speaker.

The total gain is easily arrived at by simply adding the individual gains and losses in the circuit. Thus, after leaving the microphone, the gains are

$$43 + 67 = 110 \text{ db.}$$

The losses are confined to the insertion loss -12 db. The net gain is 98 db.

The power level at the input is -90 db. This is brought up to a level of $+8$ db feeding the speaker. If we are experienced in the use of such units we know at once that this is a rather low speaker volume.

Example 4: The decibel is fundamentally a measure of power ratio, and, therefore, in expressing current or voltage ratios in decibels, it is necessary to write the current or voltage expressions so that they indicate the powers involved. The derivation of these formulas will become clear by studying this example.

Let P_1 equal the power input, P_2 the power output, and R_1 and R_2 the input and output impedances, respectively:

$$\text{db} = 10 \log \frac{P_2}{P_1}$$

but

$$P_1 = \frac{E_1^2}{R_1} \quad \text{and} \quad P_2 = \frac{E_2^2}{R_2}$$

Therefore,

$$\text{db} = 10 \log \frac{E_2^2/R_2}{E_1^2/R_1} = 10 \log \frac{E_2^2 R_1}{E_1^2 R_2} = 10 \log \left(\frac{E_2}{E_1} \right)^2 \times \frac{R_1}{R_2}$$

but

$$\begin{aligned} \log X^2 &= 2 \log X \\ \text{db} &= 20 \log \frac{E_2 \sqrt{R_1}}{E_1 \sqrt{R_2}} \end{aligned}$$

Similarly,

$$\text{db} = 10 \log \frac{P_2}{P_1}$$

but

$$P_1 = I_1^2 R_1 \quad \text{and} \quad P_2 = I_2^2 R_2$$

Therefore,

$$\text{db} = 10 \log \frac{I_2^2 R_2}{I_1^2 R_1} = 20 \log \frac{I_2 \sqrt{R_2}}{I_1 \sqrt{R_1}}$$

It is seen in both of the above derivations that the impedance values cancel out only if the input and output impedances are equal, which need not necessarily be so.

When the input and output impedances are equal, the expressions may be written, $\text{db} = 20 \log E_2/E_1$ and $\text{db} = 20 \log I_2/I_1$.

In order to facilitate decibel calculations, it is customary in telephone and radio practice to assume arbitrarily the value of 0.006 watt (6 mw.) as 0 db.¹ Hence, unless some other level is indicated as 0 db, the level 0.006 watt is to be assumed. The statement that an amplifier delivers 0 db to its load would, therefore, be taken to mean that it has an output of 0.006 watt. Note that such a statement tells nothing concerning the *gain* of an amplifier, but it is, nevertheless, a convenient way of rating its output.

Example 5: It is desired to find the power output in watts of the dynamic microphone, previously mentioned as having a level of -90 db. In this example, as in Example 2, it is necessary to reverse the process employed, to find the decibels. Note carefully how this is done:

$$\begin{aligned} 90 &= 10 \log \frac{0.006}{X} \\ 9 &= \log \frac{0.006}{X} \end{aligned}$$

But the antilog of $9 = 10^9$; therefore,

$$10^9 = \frac{0.006}{X} \quad \text{and} \quad X = \frac{6 \times 10^{-3}}{10^9}$$

so

$$X = 6 \times 10^{-12} = 6 \mu\mu\text{w}$$

Example 6: If the output of vacuum tubes were given directly in decibels, instead of in milliwatts, as in the present practice, it would be easier to compare their relative merits as sound-power producers.

¹ The power value that represents 0 db is known as the "zero reference level."

Find the decibel rating of a 71 type tube which is listed as having an output of 790 mw.

$$\begin{aligned}
 0 \text{ db} &= 0.006 \text{ watt} && (\text{reference level}) \\
 \text{db} &= 10 \log \frac{790}{0.006} \\
 \log \frac{790}{0.006} &= \log 131.6 = 2.11 \\
 10 \times 2.11 &= 21.1 \\
 \text{db} &= 21.1
 \end{aligned}$$

which is the output of the type 71 tube. Similarly, placing this in a list of familiar tubes the following comparative values appear.

Tube	Milliwatts	Decibels
71A	790	21.1
45	2,000	24.7
50	4,600	28.8

Example 7: Connecting tubes in push pull results in an output which is 40 per cent more than double the power available from a single tube. Expressed mathematically this appears as

$$P = 2 \times W + (2 \times W \times 0.40)$$

where P is the output power in watts and W the output power in watts for a single tube.

The amount of extra power secured by placing two tubes in push pull will, of course, depend on the output from a single tube. Taking the 71 type as an example, it is seen that the output is 790 mw. or 21.1 db for a single tube. If placing the tubes in push pull only doubled the output, 1,580 mw. would result which equals 24.2 db. However, connecting the tubes in push pull raises the output to 2,212 mw. which equals 25.6 db. Thus, an extra gain of 1.4 db has been secured by placing the tubes in a push-pull circuit rather than in parallel.

Example 8: In order to have satisfactory room volume, it is necessary to deliver an approximate power of 1 watt to the loud-speaker. This equals a level of 22.2 db computed as follows ($0 \text{ db} = 0.006 \text{ watt}$):

$$\begin{aligned}
 \text{db} &= 10 \log \frac{1}{0.006} = 10 \log 166.6 = 10 \times 2.22 \\
 \text{db} &= 22.2
 \end{aligned}$$

Let us assume that it is necessary to bring up to this level the output of a microphone having an output of -100 db . It is apparent that a gain of 122.2 db is necessary and that the output tube must be able to handle a power level of at least 22.2 db. Referring to the tabulation given in Example 6, it is seen that a type 45 tube would be satisfactory for this purpose.

Example 9: As the decibel is so directly related to the effect of sound on the ear, it is the ideal unit to express the fidelity rating of a transmission circuit or any of its components. For example, let it be required to calculate the fidelity of reproduction of a certain 1:1 transformer when 1 volt across the primary winding produces in the secondary at given frequencies the results which follow:

Cycles	Voltage
30	0.1
50	0.5
100-8,000	1.0
10,000	0.8

This information means very little unless translated into decibels. Giving the arbitrary value of 0 db to 1 volt the following results appear.

At 30 cycles,

$$\text{db} = 20 \log \frac{1}{0.1} = 20 \log 10 = 20 \times 1 = 20 \text{ db loss}$$

This might have been written

$$\text{db} = 20 \log \frac{0.1}{1} = 20 \log 0.1 = 20 \times -1 = -20 \text{ db}$$

This, however, would involve the use of negative characteristics which are difficult to work without a great deal of practice. It is easier, as explained before, to work the problem with positive values, that is, to put the higher value as the numerator in the fraction and change the sign in the answer. It is quite apparent that the output at 0.1 volt will be less than at 1 volt, and, therefore, the answer must be a negative value to express a loss.

Using the same method of computation and taking the voltage values from the preceding tabulation, the following results are obtained. At 50 cycles the loss is 6 db (-6 db). At 10,000 cycles the loss is 1.92 db (-1.92).

Example 10: The power of a certain broadcast station is 1,000 watts, and this power produces an audio output of 10 db (0 db = 0.006 watt) in a distant receiver. The power of the transmitter is raised to 5,000 watts. What is the output of the receiver under the new conditions?

Assuming that the audio-output power of the receiver varies directly as the power transmitted, then $P_r \propto P_t$, where P_r is the audio-output power and P_t the power transmitted. Then

$$\text{db} = 10 \log \frac{P_2}{P_1}$$

Therefore,

$$\text{db} = 10 \times \log \frac{5}{1} = 10 \times \log 5 = 10 \times 0.698 = 6.98 \text{ db}$$

Ans. New output in receiver is $10 + 6.98 = 16.98 \text{ db}$

Example 11: If it is desired to compute the voltage gain of an audio-frequency amplifier such as illustrated in Fig. 5-8(a), for example, it will be necessary to obtain the ratio of the output voltage divided by the input voltage. The complete procedure may be obtained by the reasoning that the voltage applied to the grid of a tube is dependent upon the square root of its input and output impedance ratio. Consequently the total voltage developed in the plate circuit due to the grid swing would be

$$E_{p(a.c.)} = \mu E_g \sqrt{\frac{Z_o}{Z_i}} \quad \text{volts} \quad (3)$$

Thus, since the impedance of the output winding, Z_o , must at all times be at least equal to the tube impedance R_p , the IR drop across this winding would be *one-half* of the total voltage developed in the plate circuit. Hence, the voltage developed

across the secondary winding connected to tube 2 would be

$$E_o = \frac{\mu E_g}{2} \sqrt{\frac{Z_i}{Z_o}} \quad \text{volts} \quad (4)$$

Thus the total voltage gain of any amplifier will be the ratio of the output voltage divided by the input voltage E_o/E_i , or,

$$\text{Gain} = \frac{\mu}{2} \sqrt{\frac{Z_i}{Z_o}} \quad \text{volts}$$

The numerical gain ratio may then readily be converted into decibels by referring to the decibel and amplification table in Sec. 11.22 where the letter K is used to denote the gain ratio.

As a practical example let us assume that the input transformer in Fig. 5-8(a) has a secondary impedance of 360,000 ohms. The tube is a 27 tube with an amplification factor of 9 and a plate impedance R_p of 9,000 ohms. Now, since the load impedance is at all times assumed to be at least matched to the tube impedance, we may compute the voltage amplification gain by the ratio

$$\text{Gain} = \frac{9}{2} \sqrt{\frac{360,000}{9,000}} = 28.5 \text{ voltage ratio (approx.)}$$

Referring to Tables XA and XI A we may judge that a voltage amplification of 28.5 is equivalent to a gain of slightly over 29 db.

The decibel gain of a complete amplifier system may thus be readily computed by applying the equation to each successive stage as shown.

These examples show the convenience of using the decibel to give a mental picture of the gain and output power of a transmission system. The decibel may also be used to show losses, but this particular use of the decibel will be taken up in detail when attenuation networks are studied, in the next chapter.

It is evident that a thorough understanding of the decibel and its uses must be possessed by any technician handling broadcast or public-address equipment.

As a matter of practice, the student is urged, after studying this section, to convert decibel values into equivalent power values, and vice versa. For this purpose it may be assumed that the input impedance to the hypothetical system under consideration is 50 ohms, and that the output impedance is 5,000 ohms, the problems being worked in terms of voltage or current values.

Other calculations involving the decibel will be found throughout the remainder of this chapter and also in the next chapter.

II. MICROPHONES

10.8. Microphones—General Considerations.—The microphone, which is also known as a *transmitter*, is a device which changes acoustical energy, consisting of variations in air pressure at audio frequencies, into corresponding electrical variations in an electrical circuit. If the changes

in the electrical circuit follow the sound impulses exactly, the microphone is said to have *perfect fidelity*.

Before dealing with microphones in particular, let us examine the general conditions which they must fulfill.

If it is desired to reproduce with absolute fidelity the sound generated by a symphonic orchestra, which contains practically all the frequencies likely to be encountered in music, the microphone would necessarily have to respond equally well to all audio variations from 30 to 15,000 cycles or even higher. It is also important that no extra frequencies not present in the original be added in the microphone. Such addition is known as *harmonic distortion*.

If all the frequencies from 60 to 8,000 cycles are present in proper proportion, the results will be very realistic and the quality of reproduction high. Indeed it will probably be quite satisfactory to the average listener if all the frequencies between 60 and 5,000 cycles are reproduced alike. In order to recreate speech satisfactorily frequencies from 60 to 5,000 cycles should be present. However, frequencies from 3,000 to 5,000 might be lost without impairing intelligibility to any great extent. The frequency range from 60 to 300 cycles affects the naturalness but not the intelligibility of the reproduction.

A microphone must be capable of reproducing great variations in sound pressure without distortion. A symphony orchestra at full volume may exert a pressure of 300 dynes per square centimeter on its diaphragm. The average studio program will produce 10 dynes per square centimeter, and probably the lowest pressure to which it is expected to respond is 1 dyne per square centimeter.

If the microphone itself generates any sound, such as a hiss or a sputter, this sound will be noticeable in the background of soft passages of music, and during dead air, unless it is at least 40 db below the weakest signal encountered.

It is desirable to locate the amplifier at some distance from the microphone. This at once makes the output impedance highly important. For maximum power transfer the impedance of the microphone and its load must match; hence high microphone impedance necessitates high load impedance. Any connecting line between microphone and amplifier will possess distributed capacity; this may be roughly considered as a condenser of equivalent value across the load.

Let us see what the effect of this distributed capacity is, by taking as an example two microphones having exactly the same characteristics, except that the impedance of one is 50 megohms, and that of the other 50 ohms. They are each connected to an individual amplifier, matching their impedance, by a microphone cable having a distributed capacity of 31 mmf. per foot, and which is 30 ft. in length, giving a total distributed capacity of 930 mmf. across the load.

The microphones deliver the same output at 50 as at 10,000 cycles. Consider the 50-ohm unit working into the 50-ohm load. If there were no distributed capacity in the cable the same energy would be delivered to its termination at all frequencies, but at 50 cycles the distributed capacity of the cable under consideration presents a reactance of about 344×10^4 ohms ($X_c = 1/2\pi fc$), and at 10,000 cycles one of about 17×10^3 ohms. If we take the energy delivered by a hypothetical non-capacitive cable as standard, the power loss occasioned at the highest frequency by the use of the considered cable will be about 0.5 per cent. At the lowest frequency it will be less than this. Thus a much longer cable than the one considered may be used with the 50-ohm microphone without noticeable effect on the frequency response of the system or too great an energy loss taking place.

Considering again, the 50-megohm microphone, if the cable possessed no distributed capacity, the energy delivered would be the same at all frequencies. Let us call this energy level 0 db. At 50 cycles the loss introduced by the 30-ft. cable having 930 mmf. capacity, will be about 24 db. As the frequency increases, the loss will increase, until, at 10,000 cycles, it will be about 70 db. With a microphone of such high impedance it can be seen that a connecting cord more than a few inches long cannot be used unless special precautions are taken against distributed capacity.

The foregoing theory applies equally well to program transmission lines and is one reason why the impedance of apparatus working into or out of such lines is kept low, if this is at all possible.

The student is urged to check the foregoing statements mathematically for the practice it will afford.

The position of the various microphones in the studio system is shown in the block diagram of studio and control-room equipment (Fig. 11-2).

Output levels in decibels of the various types of microphones and pickup devices as given in this chapter are average values. As such they may not be exact when applied to devices of a specific type of manufacture as changes in design are constantly being made.

10.9. Carbon Microphone.—The operation of this type of microphone is based upon the phenomena involved when the pressure is varied upon a pile of carbon granules. The resistance of the pile varies directly as the pressure exerted upon it. If a diaphragm is so arranged that the audio-frequency waves impinging upon it cause a variation in pressure on a carbon pile which is carrying an otherwise steady current, variations in that current will occur. These will be a faithful reproduction of the diaphragm movement in amplitude and frequency. In order, however, to have the diaphragm movement a faithful reproduction of the audio wave, that unit must be tightly stretched to eliminate mechanical resonance at the lower frequencies. This limits its displacement to a great degree and lowers the output level otherwise obtainable. Thus, in the

ordinary carbon-type telephone transmitter, where it is desired to reproduce frequencies from 200 to 3,000 cycles with a very low degree of accuracy, the diaphragm is unstretched and the output approaches 0 db, while in the broadcast model, which is faithful in reproduction from 70 to 6,000 cycles, the output is rated at -45 db.

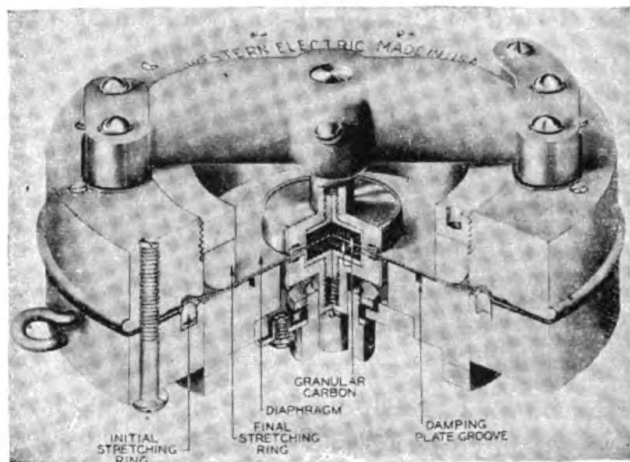


FIG. 10-2.—Constructional details of the carbon microphone.

The physical construction of a high-quality carbon microphone is shown in Fig. 10-2. It will be noted that two piles of carbon granules or buttons are employed, with the diaphragm tightly stretched between them. This design allows the microphone to be used in a push-pull circuit, with consequent advantages.

Figure 10-3 illustrates the push-pull action of the microphone. (Those unfamiliar with the push-pull principle should read Sec. 5.13 on push-pull amplifiers.) The solid arrows show the direct-current path, the wavy arrows show one-half cycle of an alternating current being generated by the microphone. These arrows would reverse during the other half cycle.

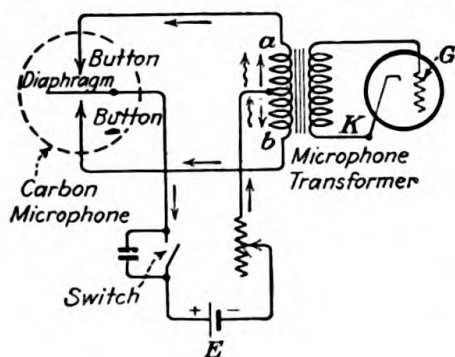


FIG. 10-3.—Schematic circuit of carbon microphone connected to amplifier.

The carbon microphone has a number of serious disadvantages. It is sensitive to vibration and cannot be readily handled while in use and must be supported on spring mounts. It is subject to "packing" of the carbon

granules. If sudden puffs or breath hit its diaphragm, this packing causes severe unbalance in the resistance of the two buttons and consequent loss of the push-pull advantages. It generates a steady hiss in its output owing to minute variations in the contact resistance of the carbon granules themselves.

In order to keep the hiss well below program level, the audio input to a carbon microphone must at all times be kept high. This is not always possible. On rare occasions, the microphone may generate a bubbling noise. This condition is due to large and sudden changes in contact resistance and is remedied in the same manner as unbalance of the button, that is, by gently shaking the unit up and down and from side to side with the current turned off. Because of these factors, this type of microphone is largely obsolete.

10.10. Condenser Microphone.—In this type of microphone, shown in Fig. 10-4, the diaphragm acts as one plate of a condenser. By its move-

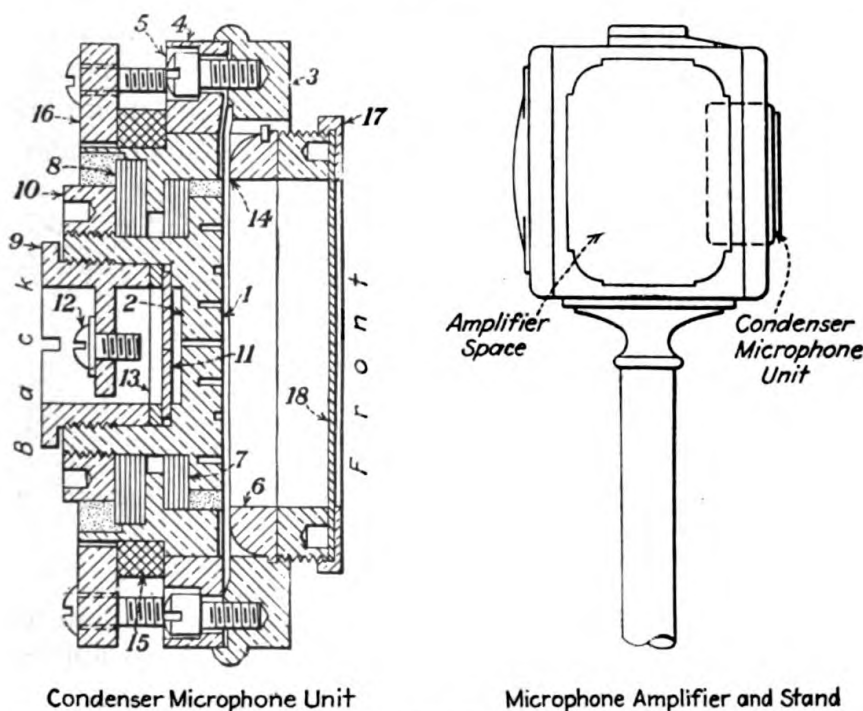


FIG. 10-4.—Condenser microphone.

ment it alters the charge and, in so doing, produces a voltage drop across a suitable resistor connected in series with it and the charging source. The voltage thus produced will be a true replica of the diaphragm movement in amplitude and frequency.

The diaphragm is tightly stretched in order to avoid mechanical resonance at undesired frequencies. The area of the diaphragm is kept small, to prevent acoustical distortion of the type referred to in the beginning of this chapter, and, despite the very close proximity of the front to the back plate, the capacity between these two units is very low.

Because of the minute movement of the diaphragm under ordinary sound pressures, and the low capacity of the condenser head, very high values of resistance and charging voltage must be employed in series with the device in order to secure the usable output. The resistor R_1 (Fig.

10-5) usually has a value of from 25 to 50 megohms and works in series with a charging potential of 200 volts. Under these conditions the output of the condenser microphone is on the order of -95 db.

The high impedance and low output of the unit make it impossible to run anything except an extremely short lead from the condenser head to its amplifier. The head and amplifier are usually mounted as a unit, and both are included under the designation *condenser microphone*.

The amplifier generally employed, and shown in Fig. 10-5, consists of two or three stages of low-gain tubes in a resistance-coupled circuit. As the total amplification behind the microphone output will probably be over 120 db before it reaches the listener's ear, it is of great importance that the amplifier be constructed to secure as quiet operation as possible.

It should be remembered that any noise generated in this unit will be of a magnitude comparable to the program level at that point and will be amplified to the same extent. For this reason it is important to keep the

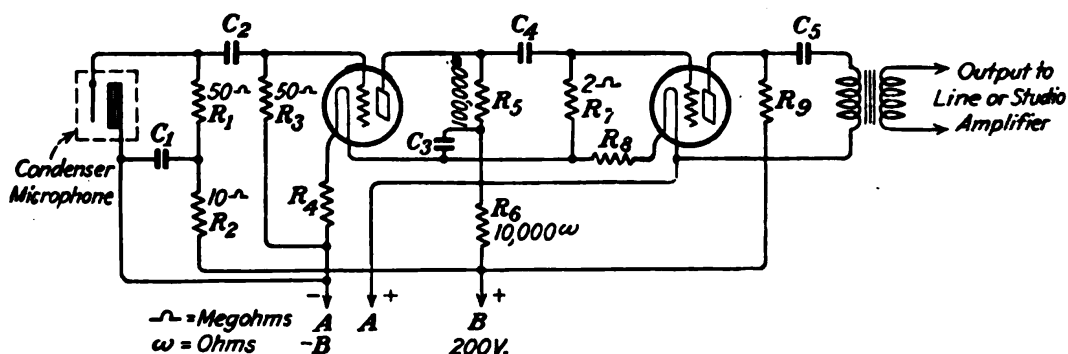


FIG. 10-5.—Condenser microphone and pre-amplifier.

microphone head free from moisture which gathers as a film across the insulation between the condenser plates and offers a variable-resistance leakage path for the charging current. This causes loud "popping" sounds in the output of the amplifier. Moisture on high-impedance parts of the amplifier produces the same effect.

The frequency response of the condenser microphone is excellent from 30 to 9,000 cycles. Extremely low sound inputs may be handled as there is no background noise present in the head itself, such as there is when using a carbon microphone.

The disadvantages of the condenser microphone are lack of portability and ruggedness; the necessity for close proximity of its amplifier; its weight, large size, and necessity for a bulky battery supply. All these factors restrict its use to studio or non-portable pickups. It requires constant maintenance and care, especially in damp locations.

The advantages of the condenser microphone are high fidelity and freedom from background noise. Because of its disadvantages, no new condenser microphones are being manufactured. However, those in service will probably remain as active equipment for some time to come.

In any event, the condenser microphone is an excellent microphone when carefully maintained. Nevertheless it is obsolete in that it is being replaced by other types.

10.11. Dynamic Microphone.—This type of microphone, also known as the *moving-coil* type, utilizes an unstretched, non-rigid diaphragm. In it, extreme latitude of movement is achieved by utilizing a number of circular corrugations of great flexibility. Because of the large displacements thus made possible, the diaphragm response at very low frequencies is excellent. The general construction of this microphone is shown in Fig. 10-6.

Rigidly attached to, and free to move with, the diaphragm is a coil made up of a large number of turns of extremely thin aluminum ribbon. This ribbon is insulated from itself and the diaphragm by means of a

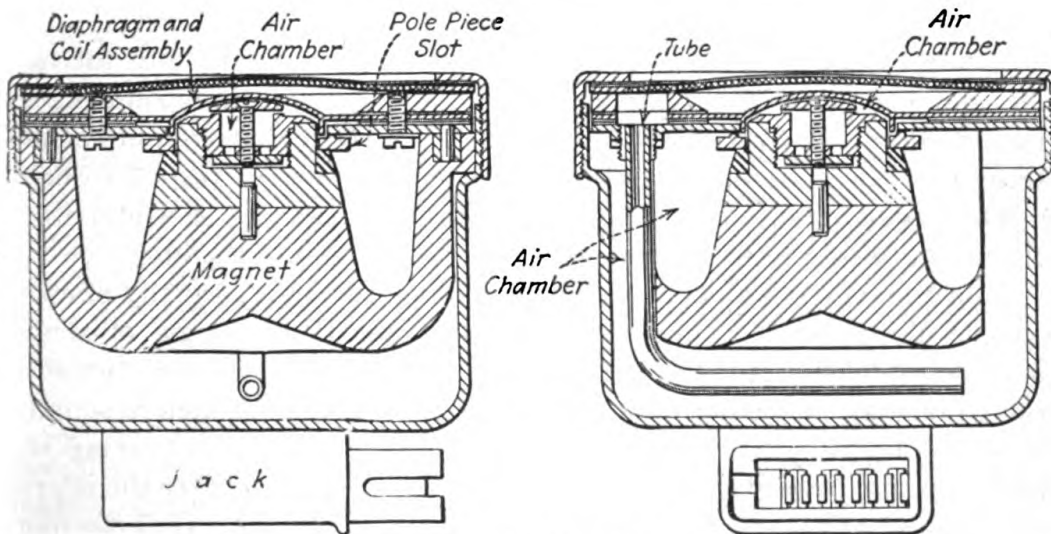


FIG. 10-6.—Dynamic microphone assembly.

suitable varnish, which is also utilized to keep the assembly together. Because the entire movable unit is of minute weight it will respond to very high frequencies. By means of acoustical damping in the microphone assembly, excellent response is obtained over a range extending from about 20 to 9,000 cycles.

The coil is arranged, similarly to the voice coil on a dynamic speaker, to pass between the poles of a powerful *permanent* magnet, made of cobalt steel. The clearance between the coil and magnet is kept small in order to provide as intense a magnetic field cutting the coil as possible.

As the coil moves with the diaphragm in proportional response to the sound waves, it cuts the magnetic lines of force between the magnet's poles. Thus there is induced into the coil a current which, in frequency and amplitude, is a faithful replica of the diaphragm movement. The current thus produced in the coil constitutes the output of the microphone.

The impedance of the coil is low, from 25 to 50 ohms, thus it may be connected to its amplifier by means of long cables without any detriment to the frequency response of the system. However, as the output of the microphone is on the order of -85 db, the cables used must be well shielded in order to avoid picking up stray fields which might interfere with this weak signal.

As there is no background noise present, the dynamic microphone can reproduce weak signals without interference. It will reproduce equally well great sound intensities without tendency to overload. It is adaptable to low-level mixing, as a variable-attenuation network of proper design may be inserted between it and its amplifier.

In practice the dynamic microphone is found to be very rugged and may be handled (gently) while in operation without producing sounds in its output. Hence, there is no necessity to mount it with spring suspension.

The great advantages of the dynamic microphone over both the carbon and condenser microphones is its dependability, independence of battery supply, and independence of constant-maintenance requirements. Added to this are the benefits of excellent frequency response, light weight, small size, and consequent portability, and its freedom from effects due to atmospheric changes. Its life is indefinitely long.

The dynamic microphone as illustrated has one defect worthy of note. Loss of frequencies occurs above 1,000 cycles as the angle of sound incidence departs from 90 degrees. This in effect makes it directional to sounds of high frequency and non-directional to low-frequency sounds. In some models, this effect has been compensated for by facing the diaphragm up toward the ceiling so that all direct sounds enter the microphone via a path across the diaphragm, thus making the microphone non-directional for direct sounds. Where the diaphragm is not so treated, the dynamic microphone should always face the sound source in order to obtain the greatest high-frequency output.

The low-frequency response of such microphones is sometimes changed by the addition of a baffle which can be placed around the diaphragm. The larger the baffle, the greater its effect in increasing the low-frequency output of the unit.

10.12. Velocity or Ribbon Microphone.—Unlike the types already dealt with, this particular type of microphone is actuated by the velocity component of the sound wave. Its mechanical construction is shown in Fig. 10-7. It consists of a very light ribbon of corrugated aluminum hung loosely between the pole pieces of a powerful, cobalt-steel, permanent magnet in such a way that the magnetic field cuts the edge of the ribbon. By allowing very small clearances, the ribbon is made free to move back and forth between the pole pieces without touching them while, at the same time, the field strength is kept as high as possible.

As the ribbon moves in proportional response to the velocity component of the sound wave, it cuts the field between the pole pieces. In this manner there is induced into it an electric current which is an exact reproduction of the ribbon movement, in both amplitude and frequency. As the resistance of the ribbon is only a fraction of an ohm, its output is transferred immediately to the primary of an adjacent transformer, matching its impedance. This transformer is considered an integral part of the microphone assembly. Its secondary impedance may be anything desired but is usually either 250 or 500 ohms. The output obtained from the ribbon microphone is about -100 db.

Owing to its low impedance the ribbon microphone may be connected to its amplifier through long cables, which, because of the low levels involved, must be carefully shielded. The microphone may also be employed in low-level mixing circuits, though the utmost precaution must be exercised to obtain sufficiently quiet volume controls.

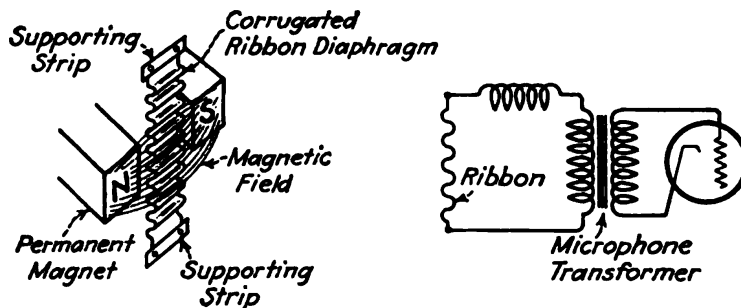


FIG. 10-7.—Velocity or ribbon microphone assembly and circuit.

The frequency response is excellent from 20 to 15,000 cycles, provided that the sound source is at a greater distance than 2 ft. from the microphone. If the source be nearer, distortion will take place causing over-accentuation of the lower notes. This characteristic makes the ribbon microphone difficult to use where bad acoustic conditions must be overcome. It also helps to effect a practical decrease in output, as performers must work at a greater distance from it than they do from other microphones.

The ribbon is actuated by sound waves moving past it at right angles to its broad surface. Such sounds form a pressure area on one side of its face and a partial vacuum on its other, the ribbon being forced into the vacuum. Accordingly, it will not be moved by sound waves traversing the ribbon in a path in the same plane as the ribbon face as such sounds will produce equal pressure on each side of the ribbon face.

As the angle of sound incidence departs from 90 degrees at either front or back, the *total response not high frequencies only*, falls, cutting off quite sharply when the sound veers around toward either side of the case. This very directional effect is sometimes valuable in helping to avoid acoustical feedback from loud-speaker to microphone when the trans-

mitter is used for public-address work. This characteristic is often of help in correcting poor studio acoustics.

The ribbon is very delicate and must be protected from sudden strong draughts or puffs of wind. To aid in this, it is surrounded by an inner and outer screen of fine-mesh silk, attached to its magnetic assembly and outer case, respectively. These and a metallic screen help protect against mechanical injury or the accidental entry of magnetic material into the assembly.

The ribbon microphone is nearly as rugged as the dynamic type and matches it in portability, ease of maintenance, and lack of background noise.

10.13. Crystal Microphone. *a. General Considerations.*—This type of microphone employs a piezo-electric crystal. Such a crystal, when properly cut, if subject to mechanical stress, shows charges of opposite polarity upon its faces. The magnitude of the charges is dependent upon the displacement of the piezo-electric body. The common crystal microphone shown in Fig. 10-8 is made up of a number of crystal cells, arranged to aid each other and so increase the overall sensitivity of the unit. The cells are so placed that the impinging sound waves cause mechanical stress in the crystals, the resultant electrical charges constituting the output of the microphone.

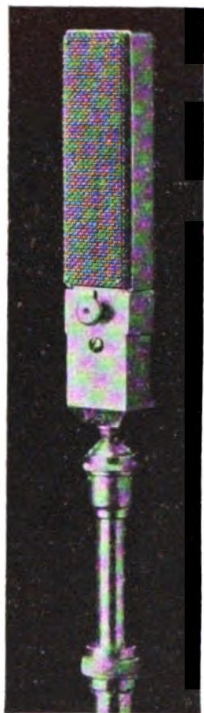


FIG. 10-8.—Studio type crystal microphone. (Courtesy of The Brush Development Company.)

The crystal cells are so connected that while the effect of the sound wave on one cell is multiplied by the number of cells (aiding each other for sound waves), the outputs neutralize each other as to mechanical displacement. This makes it unnecessary to use spring suspension with the crystal microphone, or to protect it unduly from mechanical shock.

The superiority of Rochelle salts over other crystals in its piezo-electric property has made its use for this type of microphone highly desirable. Although the salts are soluble in solution, rigid experiment has shown that suitable protection against moisture and humidity can be obtained by enclosing the crystal in waterproof papers and waxes.

b. Commercial Models.—The conventional types of crystal microphone employ a conical duralumin diaphragm (1) to actuate the bimorph element (2) as shown in Fig. 10-9(a). Two arrangements are used, however, namely, one in which the diaphragm is rigidly connected to the crystal, and the other in which the diaphragm exerts a varying pressure on the bimorph element through a resilient intermediate member. This microphone has been improved upon to eliminate its inherent tendency to resonate at some point in the musical-frequency spectrum owing to a pressure-doubling effect caused by reflections which in turn are caused by the arrangement of the crystals in

cells. This type is known as the *sound-cell* or *grill-type* microphone and is the one which apparently provides the ideal conditions for high-quality broadcasting.

The construction of a sound-cell microphone may be understood from the illustration in drawing (b). It consists of a rectangular frame of Bakelite (1) in each side of which is supported a thin Rochelle salts crystal bimorph unit, the crystals being supported by the frame at two points (2). The space between the crystal and the frame is sealed by a flexible but air tight ring (3) which permits the crystal to vibrate freely with variations due to sound pressure. The entire cell unit is impregnated in wax at a temperature of 140°F. to maintain the elements in an airtight and moisture-proof chamber. When the entire unit is subject to sound variations, the two sides of the crystal unit vibrate in phase with each other which produces a resultant in the generation of an e.m.f. across them in direct proportions to the sound pressure, while, if the unit is subjected to mechanical vibration or shock, the voltages generated by

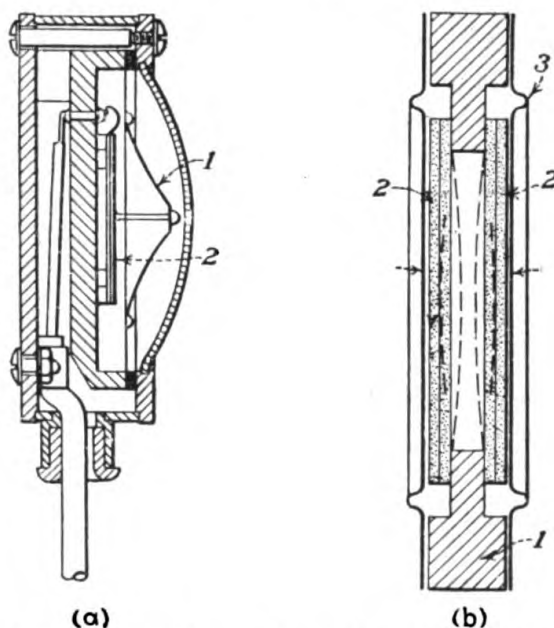


FIG. 10-9.—Crystal microphone assembly. (Courtesy of The Brush Development Company.)

both sides are out of phase with each other. This cancels any e.m.fs. generated by shock or vibration so that no voltages are developed across the input amplifier tube owing to these disturbances.

The physical dimension of the sound cells is one of the most important considerations in the design of the crystal microphone owing to the mechanical resonance condition involved. That is to say, if the sound cell has a mechanical resonance period somewhere in the musical-frequency spectrum, serious frequency distortion will result. This condition is prevented by designing the crystal units to have a natural resonance period above the highest frequency wave that is to be reproduced. In the commercial sound cells the crystal units are $\frac{7}{16}$ in. square and 0.020 to 0.030 in. thick, overall, making the combined bimorph unit of two crystals approximately 0.006 in. thick.

c. Electrical Characteristics.—The output e.m.f. developed by a single cell is approximately 0.125 mv. per plate. The impedance is highly capacitively reactive and possesses a small effective series resistance, so that its impedance value near 10,000 cycles is approximately 5,000 ohms.

Owing to the fact that this microphone is purely a pressure-operated device and therefore non-directive, there is no cutoff effect at the low frequencies and consequently it will deliver a flat frequency response over the entire audio-frequency spectrum.

The small structure of the sound cell makes distortion due to cavity resonance, phase shifting, and wave diffraction practically negligible.

In commercial use the microphone usually consists of 4 to 24 cells connected in series or series-parallel. If the leads from the microphone to the amplifier are of considerable length, the cells are connected in series-parallel, while, if the microphone and amplifier are self-contained, the cells are connected in series.

The output level of the commercial-type microphone with a 25-ft. cable varies between 65 and 74 db depending upon the cell connections.

Among the advantages of this type of microphone are its light weight, ruggedness, ease of maintenance, and the fact that no battery supply is necessary. Under no circumstances, however, can a gain control be inserted directly between the crystal microphone and its amplifier without a consequent loss in the low-frequency response.

The crystal microphone is entirely non-directional and may be used at any angle. It cannot be overloaded acoustically and has no inherent background noise.

The disadvantage of the crystal microphone is the difficulty encountered in mixing, when used with the usual type of equipment, because of its high impedance. However, the commercial diaphragm-type model, which has been discussed in this section, is very widely used in public-address systems.

10.14. Directional Microphones.—A number of directional microphones have been developed and have come to take an extremely important place in broadcasting. As pointed out in the section on studio acoustics, the use of such microphones is of great importance in that it enables instantaneous adjustment of the apparent studio acoustics.

Although there are a number of different schemes for obtaining directional characteristics, that which is universally used for studio microphones is to combine the outputs of a non-directional and a bidirectional microphone. Although this principle has been well known for a great number of years, and is exactly the same as is involved in combining the characteristics of a non-directional antenna and bidirectional loop in order to get unidirectional reception (see Sec. 7.16), it is only in recent times that its practical achievement has been possible.

In order to put the theory into practice, the two microphones involved must have exactly the same frequency response at all points in the spectrum; this is very difficult to achieve. An example of such a microphone combination would be that of a non-directional diaphragm-type

dynamic microphone placed in the same case and in close proximity to a bidirectional ribbon-type microphone.

The combined output of these two microphones, if equal, would produce a cardioid pattern, which gives a unidirectional response. A moment's thought will make this apparent, as the output of the bidirectional unit must be in phase, for sounds from one side, with that of the non-directional unit and out of phase for sounds coming from the other side. Thus, the outputs of the two microphones will cancel for sounds from one direction and add for sounds from the other.

If a switch is added to the microphone so that either unit or both may be used, the single microphone can be converted to a non-directional, bidirectional, or unidirectional unit, at will. In certain microphones, resistance components have been introduced into the circuit in such a manner that the combined outputs have been altered so that a narrower more unidirectional response pattern than that of the cardioid may be achieved. Such microphones may have more than one unidirectional response which can be selected by means of a switch.

These microphones have added so much to the flexibility of broadcast set-ups that they are coming into universal use and are rapidly rendering obsolete other less flexible types.

10.15. Lapel Microphone.—Two types of lapel microphones have been successfully developed, the carbon and ribbon varieties. They are made very small and light in weight, and are meant to be worn on the coat lapel of a speaker. By means of acoustical and electrical filters, their outputs are compensated to reduce the lower frequencies and to achieve passably accurate reproduction. In the carbon type, the granules are packed in such a manner that any mechanical movement, other than that caused by the diaphragm, is avoided. Lapel microphones are useful in their field but are avoided when highest quality of reproduction is desired.

10.16. Parabolic Microphone Receiver-reflectors.—When it is impossible to have a microphone at the source of sound, as for instance, when picking up a band marching around a football field, the parabolic microphone receiver-reflector shown in Fig. 10-10 is of great use. If the sound source is at some distance, the waves may be considered as being parallel

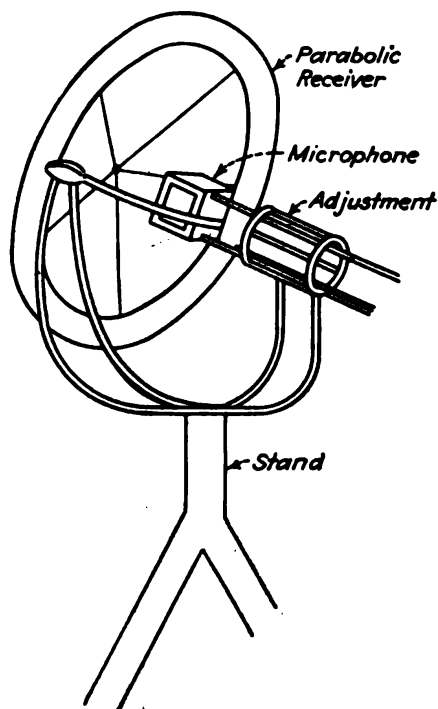


FIG. 10-10.—Parabolic microphone assembly.

without too great an error. If a microphone is placed at the focus of a parabolic receiver-reflector and the unit trained upon the distant sound, the parallel waves from that source will be converged at the microphone, and all other sound incident to the receiver-reflector will be sidetracked past the microphone. The pickup will then be equivalent to that from a microphone placed near the sound source.

The beam pickup of such a receiver-reflector is quite sharp, and it is usually aimed by means of sights.

10.17. Machine-gun Microphone.—A type of microphone which has been produced in limited quantities is the machine-gun microphone, so named because of its appearance. It consists of a more or less conventional microphone unit placed at the end of a number of tubes of different lengths arranged in a bundle. The microphone is placed at the flush end of the tubes, and each tube delivers a little band of frequencies to the microphone. In this way, the desired frequency response is achieved. If the open end of the bundle is now pointed at the source of sound, the tubes, being very directional in their reception, will pick up the sound that they are pointed at and practically nothing else. This type of microphone is extremely sharp in its directional response and is used only where such a characteristic is of paramount importance.

III. ELECTRICAL TRANSCRIPTION APPARATUS

10.18. Recordings.—Modern recording practice makes possible very faithful reproduction. In fact, if proper equipment is employed, it becomes impossible to tell by listening to the program on a radio receiver whether it is originating directly from the studio or from a recording.

A system is available whereby a sponsor may have a commercial program recorded and then distributed to various stations for broadcasting purposes. This offers many advantages over chain broadcasting, as it avoids the expensive telephone-line charges which that system entails. It also enables the program to be broadcast at the most advantageous time on each station. Because of this, part of the essential equipment of every broadcasting station is apparatus capable of accurately reproducing such program transcriptions.

Recordings are made at one of two speeds, 78 or $33\frac{1}{3}$ r.p.m. The former type of record is made in a 12 in. size and plays for 5 min. As programs usually run for at least 15 min., provision must be made to enable the operator to switch from the end of one record to the beginning of the next without the change being noticeable.

The best device for attaining this end consists of a double turntable equipped with duplicate pickups and arms. These arms are geared to a pointer which, by a suitable dial reading, indicates the exact location of the needle over the record. When the pickup head is raised to clear the turntable, it locks into position and holds itself up. It is released by

means of an electrically controlled catch, and, when it falls, it operates a piston which compresses a cushion of air in a piston chamber. By controlling the rate of speed at which this air is allowed to escape, the rapidity of the fall of the pickup head can be controlled to a nicety and the needle is lowered gently into the record groove.

Switching to the right- or left-hand pickup is governed by a special fader mounted on the turntable. In the center position, both heads are "off." As the control is moved to either side, the appropriate pickup is faded in.

In operating such equipment, the needle position at which each record starts playing, as indicated on the dial, is noted. All that is necessary then is to lift the head up and set it over the record in such a way that the indicator reads the previously "cued" number. At the end of one recording, the fader is swung over to the other side. In its passage, it makes an electrical contact which releases the catch holding up the pickup. This then falls and, through the agency of the air cushion, is set gently upon the record, just as the control is starting to fade in its output. By this means a smoothly running program is assured. Less elaborate turntables are provided with only a fader, the pickups being set manually, and reliance being placed on the skill of the operator for satisfactory results.

The $33\frac{1}{3}$ -r.p.m. recordings are made on 16-in. disks which play for 15 min. As this is usually the full length of the program, no special equipment to enable rapid switching is necessary.

There are two methods of recording in use: *lateral* and *vertical* cut. In the lateral-cut record the frequency and amplitude variations of the program are carried by the undulations in the *walls* of the groove. In the vertical-cut record they are retained in the form of hills and dales in the *bottom* of the groove. The latter method is not yet in general use in commercial recording of the type under consideration. Recordings may be started either from the inside groove or from the outside groove.

The standard broadcast turntables today are equipped to play vertical or lateral records up to 16 in. in diameter and at either $33\frac{1}{3}$ or 78 r.p.m. Most units are equipped with a cueing amplifier which can be thrown into the circuit to reproduce as sound the output of the pickup without its going through the regular broadcast channels. The operator sets the record up preparatory to putting it on the air by listening to its start on the cueing amplifier. He then turns the record back by hand until he has reached a point immediately before the start. When the time comes to put the record on the air, he holds it in position by hand, turns on the turntable, and lowers the pickup into playing position on the record.

10.19. Pickup Heads.—In general, there are two important types of pickups; namely, those employing a magnetic assembly, and those

employing a piezo-electric crystal assembly. Both of these types are manufactured to reproduce vertical or lateral recordings. A combination type to reproduce both methods of recording is also made.

The tone arms on all pickup devices should be counterbalanced in order to relieve the record of unnecessary weight to reduce wear on the record and to increase the life of the pickup head. Pickup heads may be wound to any desired impedance. For use with broadcast equipments, they are usually of 50, 200, or 500 ohms impedance and may, therefore, be worked into amplifiers or mixers without the necessity of changing their impedance. The usual output of a pickup device is -35 to -40 db. Various methods of connecting the pickup device are shown in Fig. 10-11.

To eliminate the noise caused by the needle passing over the record, a so-called *scratch filter* is employed. The scratch filter is generally con-

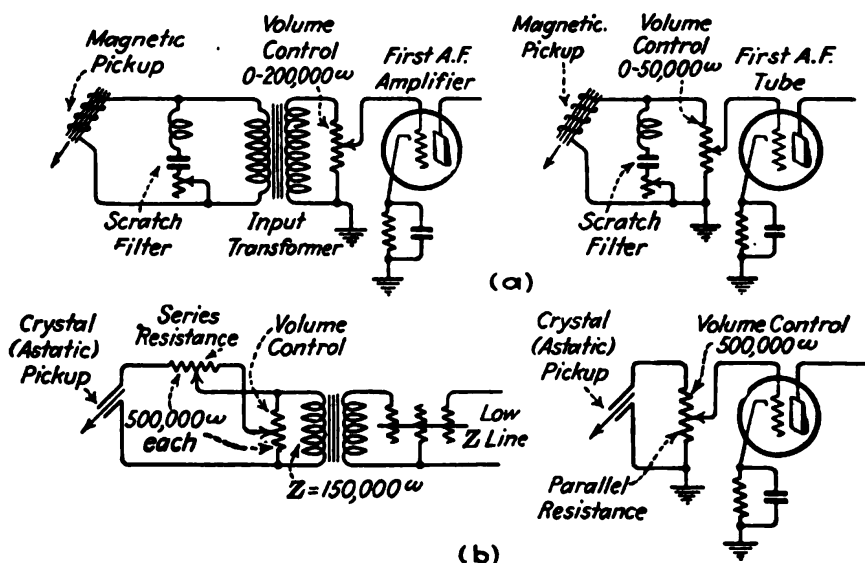


FIG. 10-11.—Methods of connecting the pick-up device to its amplifier showing scratch filters (a) and volume controls (b).

nected directly across the input transformer or pickup device to attenuate the high-frequency hissing voltages present at that point. The circuit is a simple series-resonant or equalizer circuit as illustrated in diagrams shown. The values of L and C are frequently tuned to resonate at a frequency of approximately 5,000 cycles. The filter unit is connected in series with a variable resistance to control the degree of attenuation. At the resonant frequency without the variable resistor, a small band of frequencies on either side of the resonant frequency will be bypassed through the resonant circuit, thereby decreasing the e.m.f. developed across it. Hence, if the scratch frequency is in the vicinity of 5,000 cycles, the voltage developed across LC will be small, and consequently very little energy will be delivered to the input transformer unless a variable resistor is provided as shown in right-hand diagram of Fig. 10-11(a). The various types of pickup heads will now be discussed in detail.

a. *Standard Magnetic Type.*—In reproducing a recording by the electrical method, the movement of the needle as it follows the groove variation is made to change the flux surrounding a coil in a pickup head, the counterpart of the old phonograph reproducer. In this way an e.m.f., which, in the ideal case, corresponds in amplitude and frequency to the groove variation, is induced into the coil. The most common type is illustrated in Fig. 10-12. In this type, the needle is pushed from side to side by the action of the record groove, this movement producing a corresponding variation in the armature position. With the armature in the center, the flux passes from both the upper and lower termination of one pole to the corresponding termination of the other, in equal distribution. As the armature moves to one side, it creates a new path of lower magnetic reluctance from one of the upper pole pieces to the lower pole piece on the opposite side. The flux distribution is then rearranged so that the greatest number of lines of force enter and leave the pole pieces nearest the armature. This rearrangement changes the flux distribution through the coil, inducing a corresponding e.m.f. into it. As the armature swings over to the other side, the flux is again redistributed in like manner. It will be noted that the e.m.f. induced into the coil by this change in flux will be in the opposite direction, thus completing the cycle.

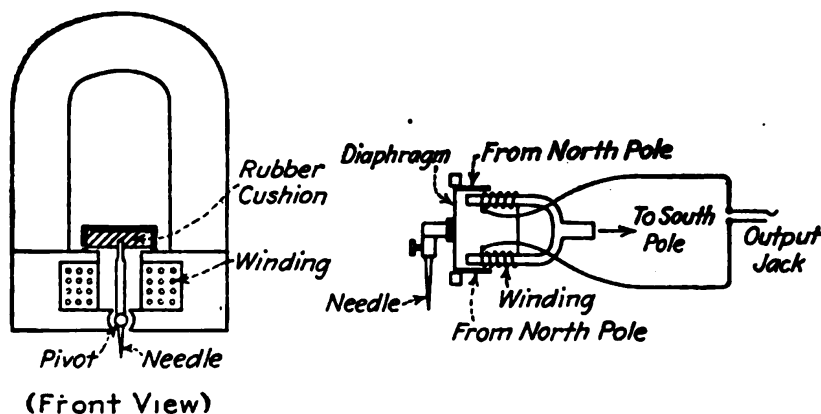


FIG. 10-12.—Standard magnetic type pick-up head.

In order to prevent the armature from being held to one side by the strong magnetic attraction to which it is subject upon once leaving dead center, some means must be provided for returning it to that neutral point. To provide the necessary damping and to return the armature, its top is embedded in a resilient cushion of soft rubber. The bearing at the lower pole piece is also formed by a sheet of rubber. Owing to the large proportion of mechanical rather than useful magnetic damping entering into this construction, the efficiency is low.

The use of rubber at such a critical point of the assembly entails some important disadvantages. Because of aging, the rubber loses its resiliency in a comparatively short period of time. As this seriously affects the frequency response of the device, its dismantling for replacement of the rubbers is necessary at frequent intervals.

Because of the mechanical design, it is difficult to make this type of unit respond to high frequencies. In the best examples, by resonating the armature assembly at about 3,000 cycles, the response is brought up at this point and falls from there to cutoff at about 5,000 cycles. At the low-frequency end of the curve the response is good down to about 80 cycles. Some pickups respond below this frequency, others have a tendency to be thrown out of the groove because of the large amplitude of the variations encountered. It must be understood that these are average curves. Individual curves will vary considerably with the age, make, and condition of the unit.

The standard magnetic type such as is found on home reproducers has the advantage of high output and low cost, but the disadvantages of poor frequency response

and very high needle-point impedance; that is, it takes a good deal of pressure to move the point of the needle from one side to the other, and this helps to rapidly break down the walls of the record and "erase" the high frequencies from the groove.

b. *Broadcast Lateral Magnetic*.—In pickups designed for broadcast use, high output level and low cost are not particularly important factors, but every effort must be made to keep the fidelity of response as high as possible, and the needle-point impedance and weight on the needle point as low as possible. Latest types use a light, non-magnetic ribbon, which may be regarded as a one-turn coil. This ribbon is placed in a magnetic field in such a way that the motion of the needle is transmitted to the ribbon, which in cutting the magnetic field has a voltage induced into it. This voltage translates the needle motion into electrical output. The needle, in the form of a permanent-jewel (sapphire or diamond) stylus, is mounted in such a manner as to pierce the center of a rubber disk which acts as its hinge. The record is thus free to move the stylus in any direction either vertical or lateral. Advantage of this fact is taken in the construction of vertical and combination vertical and lateral pickups, the needles of which are similarly mounted.

As the weight of the moving parts of such a system can be made very light, no undue amount of stiffness need be employed in order to obtain an excellent frequency response. This is just the reverse of commercial magnetic pickup practice discussed previously. The ease of movement of the needle is reflected in that the whole assembly has a very low needle-point impedance. This in turn means a minimum amount of wear on the record walls. The low needle-point impedance in turn allows the head to be made very light. Hence, the weight on the record can be kept down to an ounce or so without the danger of the pickup being thrown out of the grooves by high-amplitude low-frequency vibrations.

In practice, the actual pressure at the point of a needle may easily run into tons per square inch as the whole weight of the assembly is concentrated on a very tiny point. The low weight of pickups such as this makes it possible to use a permanent-jewel stylus, as the wear on the needle point has been cut down to a very large degree.

The ordinary shellac-base commercial record contains an abrasive which is meant to grind the steel needle into a shape that will fit the groove. If an ordinary needle is used more than once on such a record, it will be ground down to such a point that it will begin to damage the side walls. Thus it is important to change such needles after every record.

Transcription pressings are made on a plastic base such as *vinyl*, which contains no abrasive and which practically does away with surface noise. This material is relatively soft, however, and as it has no abrasive, a badly formed needle point, that is, a defective needle, will rip and ruin it in one playing. Acetate (instantaneous) recordings will react similarly.

It is for this reason that when non-permanent needles are used on such records they must be first rigidly inspected to make sure that no defective needles are used and be discarded after each playing. The inspection is carried out, usually at the factory, by casting a huge shadow of the needle point, which magnifies any irregularity thousands of times. This explains the meaning of the term *shadowgraph needle*.

With semipermanent points (very hard material), it is important never to rotate the needle once it has been placed in use as the grinding of the needle by the record develops sharp edges. If the needle is accidentally rotated, it will proceed to tear up the record.

In broadcast use, the pickup is used a great deal to play back so-called *acetate recordings* which have comparatively soft walls and wear quickly. A standard heavy commercial pickup in combination with a poor needle can easily ruin such a record in one playing. Thus, as brought out above, defective needles can always damage

any record. Therefore, the abolition of the necessity of renewing needles is a very great advantage indeed. The disadvantages of such broadcast-type pickups are low output level which makes them unsuitable for ordinary commercial use. Their price is high mainly because of their limited production. They are not too critical as to picking up magnetic hum, but must be very carefully grounded and shielded to guard against this because of their low output level.

c. *Commercial and Broadcast-type Crystal Pickups.*—The difference between the commercial and the broadcast models of crystal pickups is only in refinement. In the broadcast model, every effort is made to keep the needle-point impedance and

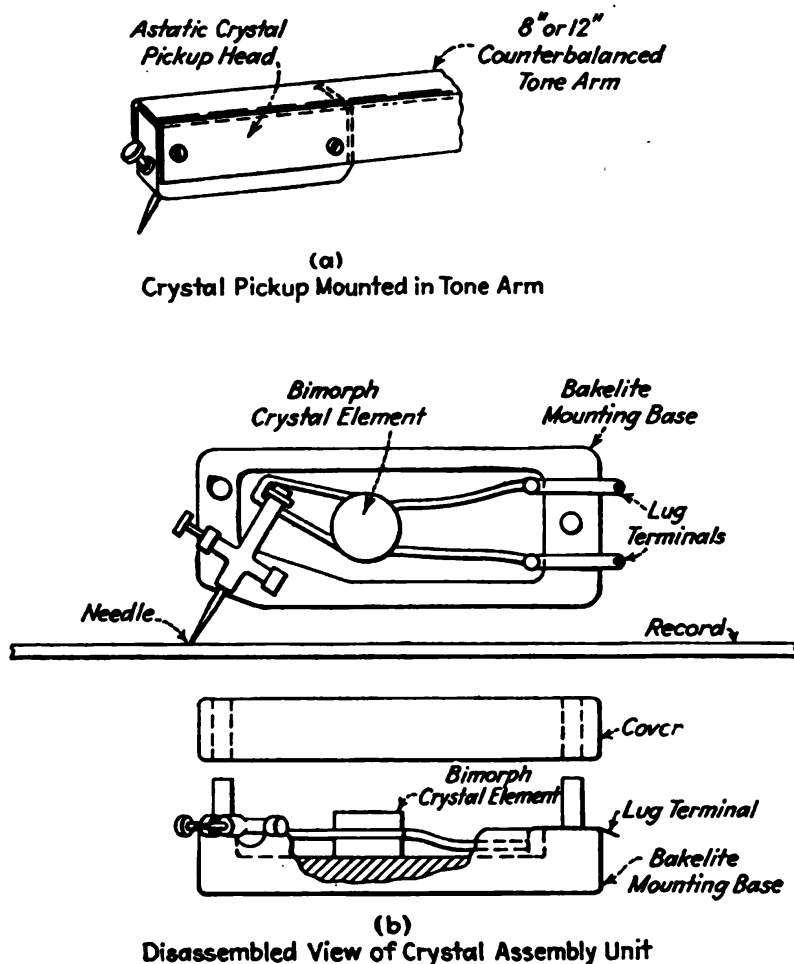


FIG. 10-13.—Crystal type pick-up head.

weight low and the fidelity high. The added cost to enable the realization of such features is not a factor.

This type of pickup, shown in Fig. 10-13, utilizes a piezo-electric bimorph crystal element to convert the mechanical motion of the needle, traveling over the record, into electrical energy.

Piezo-electric properties are explained elsewhere in this text (see index). Suffice it to say here that a piezo-electric crystal wafer under strain will produce opposite electric charges between its faces, that these charges reverse in polarity with a reversal of the direction of strain, and that their amplitude can be made proportional to the amount of strain.

The crystal, which is usually Rochelle salts, suitably protected against moisture, is so mounted that the motion of the needle produces corresponding strains in the crystal

structure. Two pieces of foil, in contact with the faces of the crystal, carry the electrical potential so generated through wires to the terminals of the unit.

The frequency response of such units can be made excellent, and because of the light weight of the parts involved, the needle-point impedance and thus the weight on the needle point can be kept low. Because of this, the unit is adapted for use with permanent styluses if so desired.

As the crystal acts as a high-impedance capacity generator, its frequency response is very greatly influenced by the nature of the load. In all cases, the manufacturer's recommendations as to the type of load for their particular element should be followed. Tone controls for this type of pickup are often in the form of load-impedance altering networks.

The advantages of such pickups is that they can be made to have a very high output, on the order of 2 volts on peaks, and for this reason need very little amplification following them. Because of their high impedance, they are particularly suitable for working directly into the grid of a tube, and thus they do away with the cost of an impedance-matching transformer. Because of their high capacity, they may be used with relatively long cords, although they are a high-impedance generator. They can be made to have very low needle-point impedance and even in commercial models adapt themselves to use with permanent needles. Because of their simple construction, the cost is relatively low.

To summarize, the disadvantages are that they are apt to be microphonic and subject to acoustical and mechanical feedback, that is, to translate vibration other than that of the groove into the output. Because of this, it is very necessary to make sure that the turntable is vibrationless and that speakers are not mounted so close to the pickup that the acoustical energy may shake the pickup and thus cause feedback. Some models are very much more subject to these disturbances than others. The crystal unit must be guarded against extreme temperature rises. At temperatures around 130°F., the operation of the unit becomes erratic, and it usually begins losing output level long before this point is reached. At temperatures higher than 135°F., permanent damage to the unit may result. As Rochelle salts are soluble in water, every effort must be made to keep humidity out of the device. The manufacturer always seals the unit against humidity in so far as this is possible by coating with lacquers or by other means.

The frequency response of the unit is critical as to load, although this is no particular disadvantage if the fact is kept in mind. The high impedance of the unit complicates mixing, as usually carried out in broadcast practice, in that most broadcast microphones are low-impedance devices, which makes special handling of the pickup output usually necessary.

d. Vertical Heads.—These heads must convert an up-and-down motion of the needle into corresponding voltages. They are built very much as would be a miniature dynamic speaker with the needle substituted for the cone.

In such pickups, a coil of wire is placed in a strong magnetic field, in exactly the same magnetic relationship as a voice coil in a dynamic speaker as to its steady surrounding magnetic field and this coil is attached to a permanent-jewel stylus. This stylus is centered in a rubber diaphragm and so is free to move up and down following the indentations at the bottom of the record groove and carrying the coil with it. The coil thus cuts the permanent magnetic field surrounding it and has voltages corresponding to the movement of the needle induced into it.

To summarize, the advantages of this system are that the frequency response can be made excellent. High amplitudes can be recorded and handled by the pickups without cutting down the length of the record because the spacing between grooves can remain small and constant. For the same reason, it is possible to make longer

recordings on the same size platter, as the danger of overcutting into the next groove is avoided. In addition, the grooves may be closely spaced. The disadvantages of the system are that such pickups cannot be used to play commercial recordings and are limited to special recordings made for broadcast use.

Crystal vertical heads are also made. Their construction differs only superficially from that of the lateral heads in that the crystal unit is now placed at right angles to its former plane. Except for the change in direction in needle movement, everything said concerning crystal units applies here.

e. Vertical-lateral Heads.—The construction of the modern low-level lateral head lent itself well to conversion for reproduction of both vertical and lateral recordings. By the addition of another magnetic system in the vertical directional, and a means of switching from one to the other, it is possible to choose either vertical or lateral output.

The method of mounting the permanent-jewel stylus at the center of a rubber diaphragm, which acts as a hinge, enables the stylus to impart either vertical or lateral motion to its attached coils or ribbons, the ribbons usually forming a single-turn loop.

In essence, such pickups have their stylus impart motion to two distinct systems of coils or ribbons. The positioning of magnetic fields about these coils or ribbons is such that vertical movements of the stylus produce corresponding induced voltages in one coil and lateral motions of the stylus produce corresponding electrical currents in the other. A switch allows selection of either circuit.

To summarize the advantages, a single vertical-lateral pickup may be used for all types of recordings. The fidelity of the system can be made as good as or better than that of single vertical or lateral pickups. In fact, the function of the equalizers usually associated with such heads does not consist of boosting any particular frequencies that may be lacking, but of cutting down the frequency response of the unit, which is actually better than that of the recordings it is reproducing. In other words, the elimination of a greater frequency response than is necessary to reproduce the frequencies actually on the record is desirable from the standpoint of reducing surface noise. Such noise does not occur at any particular frequency, but is equally present over the whole frequency range. It may sometimes give the impression that it is present to a greater extent at some particular frequency in that if the reproducing mechanism has strong resonant points the surface noise will naturally produce greater outputs at these resonant points than at other places in the spectrum. The needle-point impedance and weight of such a unit may be kept very low, and permanently jeweled styluses are used.

10.20. Pickup Equalization for Different Systems of Recording.—In general, there are a number of different frequency-response systems used in recording, each having its own particular set of advocates. As a result a pickup which has a characteristic such as to give admirable output for one system of frequency response will require adjustment to do equally well for another.

For example, in making lateral recordings the lower frequencies require that a greater spacing between grooves be used than that required for the high frequencies. If the lower frequencies were recorded at the same amplitude as the high, it would be necessary to make the spacing between grooves very great. It would also be difficult to keep the pickup tracking in the groove at the low frequencies.

Thus, it is customary practice to reduce the amplitude of the cutting stylus for frequencies below about 400 cycles, in a uniform manner, down to the lowest frequency being recorded. There are various practices as to the rapidity with which this reduction is carried out and the exact point at which it starts. For some types of pressing material, it is impractical to try to reproduce the very highest frequencies, and a 5,000-cycle cutoff may be indicated. For other materials, it may be entirely practical to go up to the highest frequencies.

As indicated in the preceding section, it is not desirable to have any higher frequency reproduction from the pickup than is necessary to reproduce the highest frequency recorded, as it only results in a higher average level of surface noise. Another consideration in this respect is that many recording heads have a high order of harmonics present at the frequencies above their useful range. Reproducing of the frequencies above the useful range of such recording heads gives a very annoying form of distortion which would not be present if a sharp cutoff band-pass filter were inserted to eliminate the unwanted harmonics. For these reasons, equalizing systems are used on all types of pickups so that the characteristics of the pickup may be changed to suit the particular record being played. An effort is being made to standardize the number of systems in use.

Scratch filters should ideally be band-pass filters with a sharp cutoff at the high-frequency end occurring just above the highest frequency to be handled. Unfortunately, such units are rare and difficult to work out in practice. The conventional scratch filter as applied to the ordinary phonograph reproducer is simply a means to reduce the high-frequency response. It does get rid of a great deal of scratch, because it restricts the frequency response covered by the instrument. It also sacrifices the recorded high frequencies.

10.21. Expansion Systems.—In commercial recording, it is necessary to compress the natural volume range of music which normally covers an extent of about 70 db to a variation of around 45 db. This is necessary so that low-volume sounds will not be covered up by surface noise and so that the high-volume sounds will not cause the recording needle to cut into the next groove. The compression is accomplished by having an operator ride the gain control just as is done in a broadcasting studio.

In an effort to give a greater dynamic range to recorded music, volume-expansion systems are sometimes used in high-quality reproducers. Of course, they cannot be used over the air because it is necessary to contract the volume range in broadcasting as well as in recording and, therefore, they must be used at the listening end of the system. These systems consist essentially of some means of increasing the volume automatically for the loud passages over that which it would be normally.

In essence, a part of the audio-frequency output of the amplifier is impressed upon a detector system so that the greater the audio-frequency input, the greater the direct-current output of the detector. This in turn is used to vary the output level of the amplifier automatically, usually by being used as an additional bias for a variable- μ tube in one of the amplifier stages or by some other means such as reactor saturation.

A time delay in the circuit, usually on the order of $\frac{1}{10}$ to $\frac{1}{4}$ sec., is necessary so that the AVC action will not erase the audio-frequency response of the amplifier. The system is usually adjusted so that it does not respond in any degree to low volumes, but starts working in the middle-volume range and increases its output sharply as the volume range goes higher. Thus, the low-volume passages are pretty well left alone. The middle-volume passages are brought up, and the louder passages are brought up in increasing proportion to their recorded loudness. This system is a compromise system in that it cannot possibly follow the variations in an original level as controlled by the human factor inherent in an operator. But when properly designed and properly used, it does produce some remarkably fine results which are not apparent on the face of the system.

The effective surface noise is very materially reduced. If the average volume level of the record has been very much raised, and if the volume control is adjusted for normal maximum-level operation, then the surface noise is reduced by approximately the amount that the maximum level has been brought up. The restoration of dynamic range to the music is of great importance as many musical compositions depend very greatly for their effects on the utilization of the full dynamic range of the orchestra.

10.22. Instantaneous Recording.—Because the turntables used adapt themselves and because there is a need for the service, most broadcasting studios also have instantaneous-recording outfits.

Recordings are usually made on cellulose nitrate lacquer which has been applied to a disk of aluminum or glass. This type of record is usually misnamed acetate. The lacquer is very soft but hardens quickly after being cut and is hard enough to be played back immediately after cutting. Hence, the name *instantaneous recording*.

These disks do not keep indefinitely without hardening and should be stored in hermetically sealed cans to prevent their drying out before being cut.

Records may be cut from the inside out or from the outside in at $33\frac{1}{3}$ or 78 r.p.m. Practically all instantaneously recorded disks are lateral cut.

There is another type of recording, which should be mentioned, which is generally used for purposes of keeping a transcript when high-quality reproduction is not necessary. Such records are usually cut on blanks having a base of paper which is coated either with nitrate lacquer or some

other similar material. In order to get as much on the record as possible, they may be cut at a constant speed, that is, the actual speed of the turntable is designed to change as the cutting head travels across the record so that the speed of the needle over the groove is constant. In this way, the fidelity of the recording is the same at any speed. Normally this is not true, as the greater the groove speed, the easier it is to get good high-frequency reproduction. With constant-speed recording, it is possible to get a very great playing time from a given record size provided that the fidelity requirements are not too high.

It is not intended to make this a treatise on instantaneous recording but only to provide sufficient information to enable the operator who is faced with the task of making records for the first time on such a machine to turn out a creditable job and to enable him to maintain such equipment intelligently. The following list covers the main points.

a. The cutting stylus may be either a steel needle or a jeweled needle. The steel needles require frequent replacement and are not generally used, except on home recording machines. The sapphire needle, although it must be carefully handled when being lowered on the record because of its brittleness, gives a more economical and satisfactory life. All needles that produce a quiet cut with a satisfactory frequency response are good. Some needles will not do this even when new, and the average life of the needle before it requires resharpening varies a great deal. The criterion of needle life is that a good needle makes a quiet cut and a dull needle a noisy cut, that is, a record with background noise.

b. The needle should be inserted with its flat face on the cutting side, that is, so that it is cutting against the rotation of the disk. Its angle should be just off the vertical by a few degrees and leaning in such a direction that the record rotation will not cause it to dig into and jam itself into the surface. This angle may be adjusted slightly for different makes of recording blanks to produce the quietest cut.

c. Provision is always made on the machine for adjustment of the weight on the point of the cutting needle. This should be set so that when the needle is cutting at normal speed it is producing a thread about as thick as a coarse human hair or a fine horse hair. The thickness of this thread will naturally vary slightly from the inside to the outside of the record, and the adjustment may have to be changed for 33 $\frac{1}{3}$ - and 78-r.p.m. cuts.

d. The cutting process itself should be practically inaudible. A needle that cuts noisily, that is, with a hissing sound, will produce a high background noise. A needle that cuts inaudibly will produce a cut with little or no background noise. Three things can cause a noisy cut: (1) a dull needle, (2) old record stock, (3) insufficient input level. For the latter, there is no excuse as it is very easy to check and keep normal. Constant watch must be kept against the first two considerations, and a method of doing so is outlined in the next paragraph.

e. A check may be kept against the use of noisy needles by selecting an excellent needle and keeping it as a reference. The noisiness of a cut is due to a great extent to some circumstances which cause the needle to chatter. Just as a dull cutting tool on a lathe produces chattering or an unclean cut, the fact that the needle is not cutting cleanly will produce vibrations in it.

Needle performance may be checked by making test cuts, at about the same point in a good blank, with the reference needle and that being checked. While cutting, the cutting head is electrically connected to the input of an amplifier. The

vibrations of the cutting needle are translated into electrical output, and the noisier the cut, that is, the greater the movement of the needle, the greater the output will be.

Thus by using the cutting head as a pickup, while making a blank cut, and checking the amplitude of the cutting-needle vibrations generated, by means of an amplifier of known gain and a DB or VU meter, any needle can quickly be compared in its performance against the standard reference needle. The comparison needle should, of course, be used for no other purpose.

The same method is used to compare record stocks. A notation is made of the cutting output (as described above) of the reference needle on a good batch of stock. All other stocks can then be compared. It is good practice to calibrate the stock when received and again occasionally as it is being used.

As surface noise varies greatly with groove speed, points close together on a blank must always be used with either of the comparison methods outlined.

f. The input level required to do the work for any particular head is always stated by the manufacturer, and many units are quite critical as to their overload characteristics. Therefore, the manufacturer's recommendations should be observed until experimentation with the head indicates what liberties may be taken. Input levels for cutting heads will be in the order of +10 to +16 db, with 6 mw being taken as the reference level. Some heads may take a good deal more than this and some a good deal less. The impedance of heads is usually either a voice-coil impedance, that is, 2, 6, 8, 15 ohms, or thereabouts, or 500 ohms.

g. The speed of the groove past the needle is one factor in determining the high-frequency response that it is possible to obtain on a record. This is due to the fact that the sine wave drawn by any given frequency will use less and less longitudinal space on the groove the lower the speed at which it is being cut. The sine waves drawn by the higher frequencies may become so sharply peaked that the needle point is too large to follow them to the extremes of their amplitude. Thus, harmonic distortion is produced by such cuts, and no amount of equalization can serve to bring up the response satisfactorily. It is for this reason that the quality of the outside grooves of 33 $\frac{1}{3}$ -r.p.m. records is very often noticeably better than that of the inside grooves. Some recording turntables have an automatic means of increasing the high-frequency input to the cut as the head moves toward the inside grooves, and in other cases manual compensation of the equalizing system is resorted to. In either case, it is not a complete solution of the difficulty, but may be of some help.

h. "Wows," or a rhythmic change in amplitude, will be caused if anything happens to change the speed of the groove in a rhythmic manner during recording or playback. There are so many things that may contribute wows that it is almost impossible to list them, and detective work must be done in each case to track down the condition responsible. In every case, the wow will be caused by a slowing down or speeding up of the groove. To list some causes, wow may be due to dynamic unbalance of the table, off centering of the record blank, dragging of the record on loud passages, or out-of-roundness of the rubber idler or driving wheel, owing to its being left in prolonged contact with the turntable at one point during periods of idleness.

i. Removing the shavings from the recording can be one of the most troublesome of all items to the inexperienced recorder. When cutting from the inside toward the outside, the least difficulty with thread is experienced, for as soon as it appears, it may be brushed toward the center of the disk. The natural tendency after that will be for it to wind itself around the center shaft. An occasional light brushing toward the center with an ordinary paint brush is all that is necessary to keep the thread from becoming entangled with the needle, as the needle tends to throw it off toward the inside of the record. When cutting from the outside toward the inside, the needle will be continuously moving toward the thread it has thrown out. If the proper precautions have not been taken, it will start cutting over it, and soon the whole cutting

head will be hopelessly entangled. This will be sufficient to lift it out of the groove it is making and to cause it to be bounced around. Skillful operators can remove the thread or keep pushing it out of the path of the needle. However, trouble is usually encountered sooner or later in either of these processes. Probably the most foolproof method is to take a brush, such as a crumb brush, and make a stand for it which will keep it lightly brushing the entire surface of the record. It should be placed so that it is radially across the record just a few inches behind the cutting head. The thread will then travel down to the brush and be caught by it and pile up against it. The brush is never lifted until the recording is finished, but the thread may be safely removed from time to time.

j. Although nitrate disks in themselves are not particularly inflammable, the shavings that come off during recording are *extremely* inflammable and a very definite fire hazard. They should be placed in a can of water as fast as they are removed from the blank.

k. In making recordings which are to be used as masters for future pressings, it is necessary to use a disk that is over standard size, that is, a 10-in. pressing cannot be made from a 10-in. recording blank. Special master blanks can be obtained for this purpose and are cut just as any other blank except that the outside edges (beyond the standard size) must not be used for cutting.

l. Recorders are provided with some method of moving the recording head across the record so as to produce a spiral cut of the desired pitch. This is usually done by means of a trolley carrying the head across the record on a radius from the center. The head is propelled by the means of a feed screw such as is used in a lathe. Other systems, usually used on the less expensive types of recorders, have the head on an arm similar to that used for pickups, which is swung across the record by some mechanical means. The pickup heads are sometimes set at an angle to the arms, the idea being to try to approximate the condition of cutting engendered by the practice outlined for trolley-type cutters, where the needle cuts on a path at right angles to the tangent to the groove.

The more refined machines have means of changing the pitch of the spiral, and thus the spacing between grooves, either by changing the feed screw or by some instantaneous method. This is an advantage in that it is desirable to keep the space between grooves wide so that loud passages may be handled without the danger of cutting into the next groove wall. It is also desirable to keep the space between grooves as small as possible so that the maximum time may be recorded on a given size blank.

If the operator is enabled to make a choice in selecting operating features, he is better able to meet any situation. The instantaneous change in pitch feature is a nice refinement in that it allows the pitch to be kept close for the bulk of the record and to be increased where known loud sections are expected. One limit to the closer spacing of grooves is that cutting one groove may distort the walls of another already cut, by pushing it out of shape. This usually results in an echo effect when the record is played.

m. Another refinement which appears on some machines is a spiral attachment that allows the groove to be changed into a very wide spiral at the end of the record, or between different sections of a record, with a continuous circle formed at the last groove in the spiral. By its use, it is not necessary to have a long row of empty grooves at the end of a record to prevent the pickup from immediately running off the record and perhaps damaging it. The needle may be made to travel quickly toward the inside of the record and then run continuously in the last groove.

n. In checking the frequency response of any particular recording head, it is customary to drive the head by putting a constant input level of varying frequency into the driving amplifier. What the head actually produces on the record will be a

proof of its performance. Because the output of the ordinary pickup may be full of resonance points and otherwise extremely irregular, it is often difficult to judge what amplitude has been produced on the record by playing it back through a volume-indicator equipped amplifier. A much more satisfactory means is to judge the output level of the different frequencies on the record by viewing it at an angle against a normal light or preferably a polarized-light source. The width of the band of light reflected by the record grooves is an indication of the amplitude recorded. Thus, by comparing the width of the band of reflected light for different frequencies, the differences in amplitude between these frequencies can be judged. To make measurement easier, each frequency to be judged is usually recorded for a set number of grooves. Rulers scaled in decibels can easily be made to get accurate measurements of recorded levels.

o. In connection with the above, it should be noted that many cutters give admirable results on steady sine-wave inputs because the effect of the original inertia of the cutting system has been overcome and wiped out. However, such cutters may give very poor results under transient conditions such as are normally encountered in recording music and speech. Thus, the frequency response of a cutter to sine-wave inputs gives only a very partial story as to its performance under working conditions, and a system of studying its transient response would be much more to the point.

CHAPTER 11

BROADCAST CONTROL ROOM

As its name implies, the control room of the studio end of the broadcasting system is the center at which converge the outputs of the microphones or other pickup devices, and from which these outputs are distributed to the radio transmitters and to adjunct lines when chain broadcasting is involved.

I. TRANSMISSION SET-UP

11.1. Control-room Requirements.—A typical control consolette is shown in Fig. 11-1. The position or sequence in the circuit of the various

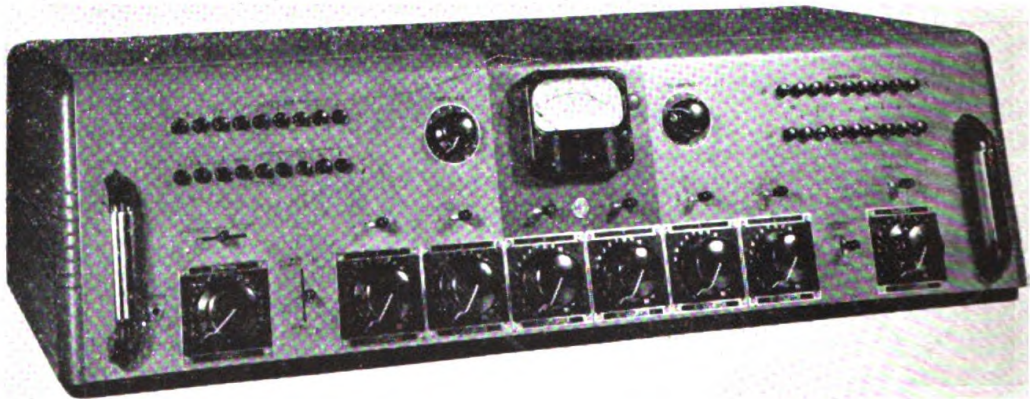


FIG. 11-1.—RCA Type-76B control consolette.

pieces of apparatus is shown in the block diagram of Fig. 11-2. In order to secure better coverage, the modern broadcast transmitter is usually situated out of town. In this way the antenna is removed from close proximity to tall steel buildings and other structures which would act as reflectors and absorbers of the emitted wave and cause a very irregularly distributed and restricted service area.

On the other hand, in order to be accessible to the required talent, it is necessary to have the studios situated at a convenient point in town. Therefore, to carry the program to the distant transmitter, privately leased telephone wires which are especially prepared for radio service are required. The special treatment of these wires will be discussed later.

To avoid serious cross talk, that is, leakage from one line to another through inductance or capacity between them, the telephone company

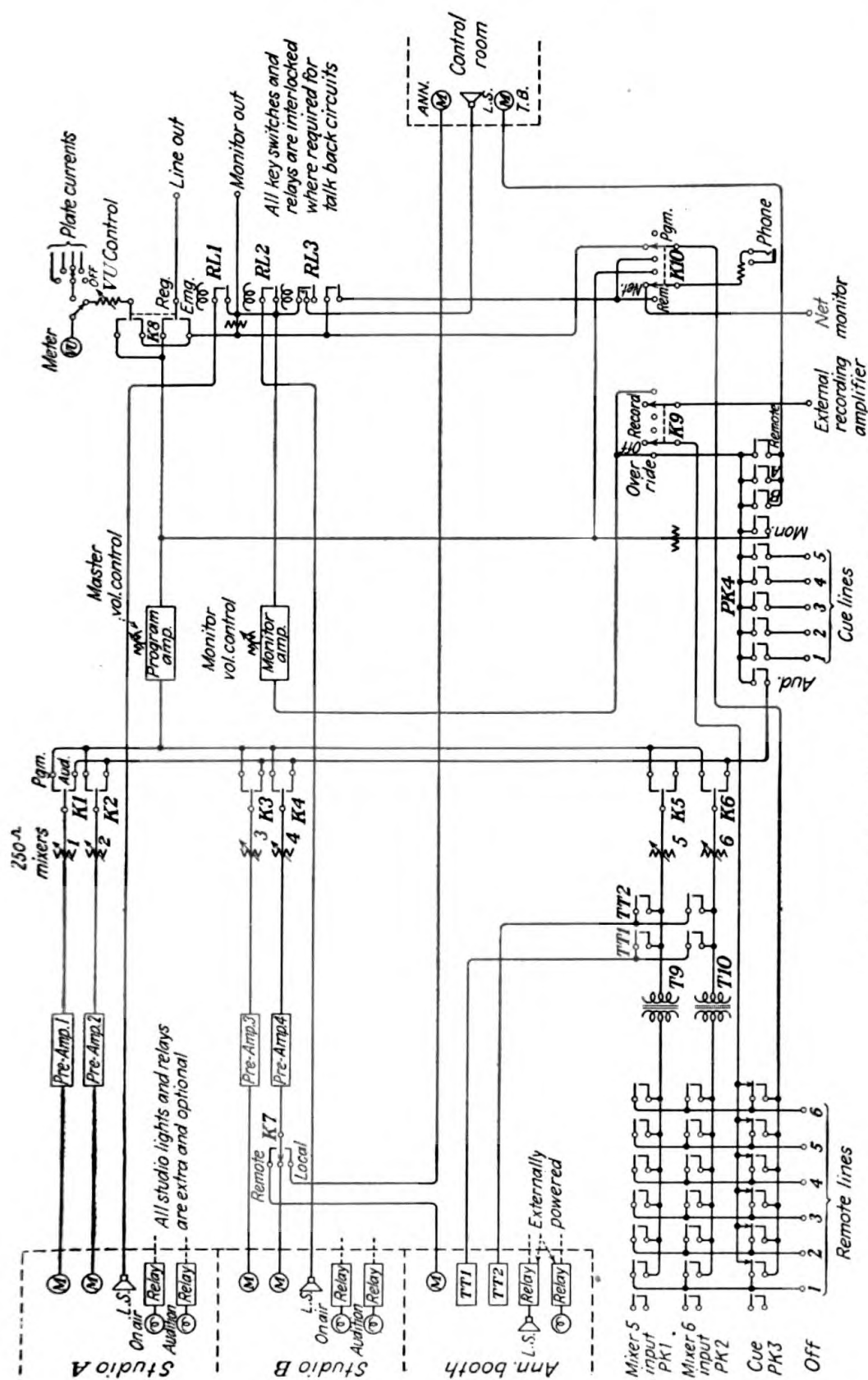


FIG. 11-2.—RCA Type 76B console block diagram.

limits the normal program level to 0 db (0.006 watt) and its peak value at any instant to +2 db.

If the gain of the amplifying system were set so that the loudest passage in a program gave a line level of 0 db and modulated the transmitter 100 per cent, the program could be transmitted with absolutely faithful sound values. This, however, would not be satisfactory for several reasons. Only those persons who were situated so near the transmitter that the weakest signal broadcast was 10,000 times stronger than any extraneous noise caused by static, hum from the set itself, or any other reason would be able to receive a perfect program, free from any annoying background noise.

As the satisfactory range of a transmitter is dependent, among other things, upon its average modulation, it is desirable to keep this as high as possible. By manually controlling the gain of the amplifying system, bringing up the level of the softer passages in the program, and necessarily decreasing that of the louder passages to prevent overloading, the average modulation is increased to a point which makes it possible for thousands of additional listeners to enjoy reception unmarred by noise.

It must be pointed out that with such transmission it is impossible to have faithful sound values. For instance, in reproducing a large symphony orchestra, a volume range of 60 db may be encountered between the loudest and softest passages. This is compressed to a range not exceeding 30 or 40 db by manual control. Thus "crescendo" and "pianissimo" effects are much modified during transmission, a fact sometimes painful to the true musician, but generally unnoticed by the layman. Naturally an unskilled operator at the gain control may easily ruin an otherwise perfect program. These drawbacks are far outweighed, however, by the many advantages the system affords.

In order, then, to modify the amplification and to keep the program on the line between studio and transmitter at the proper level, the transmission network must be provided with a volume-control and a level-indicating device. To vary the volume smoothly, the changes must take place in such small steps that the listener's attention will not be drawn to them. Controls having variations not greater than 1.5 to 2 db between steps prove very satisfactory, as does also the system of having a main control in steps of 3 db used in conjunction with a separate vernier control.

The individual units that are necessary to enable these results to be obtained and to accomplish the switching from one point to another for program input go to make up the complete transmission system.

As the ear is a very bad judge of volume and as the transmitter can be very easily overmodulated, it is necessary to have some visual system to guide the operator and indicate volume level in terms that may be easily translated into modulating levels. For this reason, the operator

at the gain control is always provided with a meter which indicates the program level at any instant. Such a meter is known as a VU, DB, or program-level meter, and the movement of its needle is a rough indication of the modulation envelope.

At the transmitter end, where the audio program is received, a so-called *limiting amplifier* is usually used. This is an amplifier so designed that its output cannot be increased over a maximum value, which may be chosen at will. The limiting action is accomplished without distortion of the wave shape. This amplifier is usually adjusted in such a manner that when the volume indicator in the studio reads "zero" (maximum program level) the output of the transmitter is being modulated to almost its full capacity. Thus, sudden program-level peaks, which ordinarily cause overmodulation of the transmitter, will not produce this effect, as the output of the amplifier will not be driven over the full-modulation point. This enables the operator in the control room to relax his vigilance and to allow an occasional peak to pass, the result being a higher average modulating level for a given transmitter.

11.2. Control-room Equipment. *a. Mixers.*—It is often necessary to use more than one microphone to transmit a program properly, and it is essential to be able to control the output of each individual microphone at will. The device that accomplishes this is known as a *mixer*. It is usually mounted near the main gain control and the volume indicator in such a position that its controls are easily available to the studio control-room operator. Sometimes this whole assembly is mounted on what is called a *turret*, which is an elevated panel placed upon a desk in such a position that the operator may vary the controls while looking into the studio through soundproof windows. The soundproofing of the control room from the studio is, of course, necessary so that the program may be monitored through a loud-speaker, enabling the operator to hear it as it will appear on the air.

In general there are two distinct systems of mixing, namely, *high-level* and *low-level* mixing. Each of these methods will be treated in detail later. In high-level mixing the output of the microphone is first amplified and then passed on to the mixer to be controlled. In low-level mixing, the microphone output is controlled without being previously amplified, and all the amplification takes place after the mixer output.

b. Speech Amplifiers.—Following the low-level mixer in the circuit is the main amplifier, the function of this amplifier being to bring the program up to line level. For purposes of transmission it is only necessary to raise the program level to 0 db, but for monitoring purposes a power level of at least 22 db is required for satisfactory loud-speaker operation. This may be arranged for in two ways: (1) the input of another separate amplifier, called a *monitor amplifier*, is bridged across the line to step the program up from line to speaker level, or (2) the main

amplifier is designed to have sufficient output to feed the speaker, and its output is then stepped down, by means of an attenuation network, to 0 db to feed the line. The calculation and design of such networks will be taken up in detail later in this chapter.

In most transmission systems, provision must be made to feed the program to more than one point. It may be required to supply several stations on a network, or several remote loud-speakers. In order to isolate any trouble which may occur, separate amplifiers are used for each program feed required. The inputs of these amplifiers are designed to have a very high impedance, on the order of 20,000 ohms; hence a number of them may be bridged across the output of the main amplifier, usually of 500 ohms impedance, without taking an appreciable amount of power from the circuit. As the amplifiers will transmit in one direction only, they completely prevent any trouble, such as a short circuit on a line fed by an individual amplifier, from producing any effect on the circuits taken care of by the others.

c. Equalizers and Line Terminating Equipment.—Besides taking programs coming from the studio, the transmission system must be capable of handling broadcasts originating at remote points, and relayed to the control room over telephone wires. Owing to the distributed capacity of the long telephone line, the high frequencies present in the program tend to become attenuated. Provision is made to correct this defect by use of filter circuits known as *equalizers*, the adjustment and design of which will also be discussed later.

In order to keep down background noises in the line, the program is impressed at the sending end of the line at about 0 db, as referred to a reference level of 6 mw. Even on long lines, this tends to arrive at the studio at too high a level for use directly into low-level equipment without overloading it. It is, therefore, necessary to make provision to lower the volume of the incoming program before applying it to the input of the equipment.

Another factor is that telephone lines are balanced to ground, which means that neither side of the line may be grounded. It is customary to insert a line-matching transformer, the primary circuit of which is balanced to ground, at the receiving end of the line. This is followed by an attenuation network to produce the desired input level.

Most control-room equipment is also balanced to ground as there are many advantages in utilizing such a system.

e. Balanced-to-ground Equipment.—If a number of conductors are being carried in a cable, there will be a definite capacity between each conductor in the cable and every other conductor in the cable, and energy may be transferred from one conductor to another through the capacity between them.

If one side of each circuit is grounded, and the wires in the cable are used to carry the other side of each individual circuit, then a great deal of

cross talk will exist between the circuits because energy from one conductor can find a return path through the capacity between itself and another conductor, and thence through the equipment associated with that conductor to ground. In this manner, it produces potentials across equipment foreign to its proper circuit. Hence, such a system is not normally used in telephone practice or where long runs of relatively high-impedance cable are required.

If neither side of the circuit is grounded, but each is kept with the same impedance to ground, and all other pairs in the cable are similarly treated, then all such paths to ground, as mentioned above, have been nullified. Such a line is said to be *balanced* to ground. Any currents striving to reach ground in a balanced line, either because they have been induced into the circuit or capacitively coupled into the circuit, will produce equal currents in both conductors, and these currents will both be flowing in the same direction. Hence, if the terminating equipment of the line is also balanced to ground, such currents flowing through it to ground will produce equal and opposite voltages across its terminals and neutralize their effects. Thus, balanced lines are the least likely to pick up stray hums and cross talk and other forms of interference. As long as the impedance to ground is balanced, it is not necessary to have any actual physical ground connection to the equipment, and it may or may not be provided in individual cases.

d. Master Control.—When a fairly large number of studios and outgoing program circuits are involved, it becomes economically feasible to have a master switching point at which all the switches necessary from one studio to another and from one program circuit to another may be under the control and responsibility of a single individual. This is known as a *master-control system*.

II. MIXING EQUIPMENT

11.3. General Requirements and Types of Mixers.—Having studied the individual characteristics of various microphones (Chap. 10), the mixing equipment to be associated with them will now be described in detail.

The requirements for a good mixer might be listed as follows, the description being based on the so-called *low-level mixing system*.

a. For maximum transfer of energy, the microphone must work into its own impedance, and the output impedance of the mixer must match the input impedance of the amplifier.

b. The impedance value presented to each microphone and to the amplifier should not vary, regardless of the position of the mixer controls.

c. The mixer should be capable of giving a smooth variation in volume from zero to maximum output. In order to accomplish this, the volume must change in steps not greater than 2 db.

d. The equipment should be capable of controlling a volume variation of at least 70 db. Half of this variation may be handled by the mixer and half by the main

gain control. These are minimum requirements. Excellent results would be obtainable by the use of a mixer control having a total attenuation of 45 db, in steps of $1\frac{1}{2}$ db, used in conjunction with a main gain control of the same value.

e. The mixer should not alter the overall-frequency response of the system with which it is used.

f. The mixer should be free from any interaction between controls, the output of any microphone being absolutely independent of the control position for any other.

g. No noise should be introduced into the circuit because of changing contacts, no matter how rapidly the gain control is moved.

h. When followed by high-gain amplifiers, it is most important that the inductance of the control units of the mixer does not pick up stray fields.

i. The insertion loss (the minimum loss due to its presence in the circuit) should be as low as possible.

All mixers fall into one of two classes: those having the controlled outputs of the microphones in series, and those having the outputs in parallel.

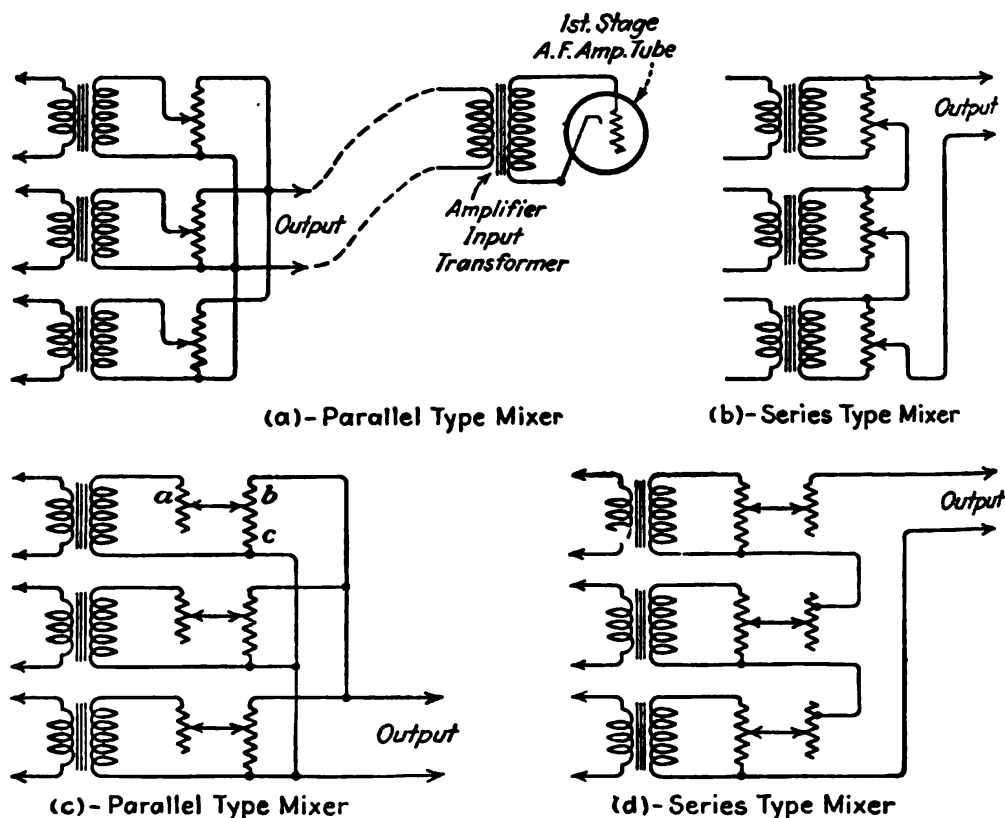
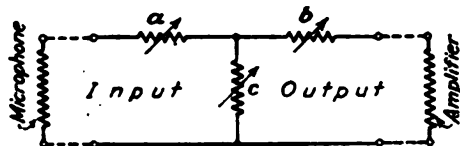


FIG. 11-3.—Types of mixers.

The simplest forms of mixers utilize potentiometers for their controls, as illustrated in Fig. 11-3(a) and (b). An inspection of these figures will reveal that our second condition for a good mixer, that of constant-impedance values, cannot possibly be fulfilled by either of these examples. This immediately obviates the carrying out of conditions a, e, and f. Such mixers are seldom used nowadays.

An improvement on these simple circuits is shown in Fig. 11-3(c) and (d). In order to keep the input and output impedance of the control unit as nearly constant as is possible, an automatic compensating resistance is used. Movement of the control knob on this type of attenuation network causes the contact arm to slide over and connect two separate resistors. These networks are comparable to variable T pads (see Sec. 11.22, Attenuation Networks) as shown in Fig. 11-4. The loss in the circuit is occasioned by the shunting effect of resistor c . As the value of this resistor is decreased, those of resistors a and b are automatically increased. Similarly, if c is increased, a and b are decreased. With a well-designed network of this type, it is possible to have the maximum impedance variation not greater than 25 per cent. In Fig. 11-3(c) the first control unit has had its resistance components marked a , b , and c , in order to bring out clearly its relation to the illustrated T pad in Fig. 11-4.

FIG. 11-4.—Conventional T -type pad.

The parallel type of mixer has gone out of favor, and a rough analysis of both types will bring out one of the reasons. Consider a four-microphone series mixer, working into a matching resistive load. Suppose a

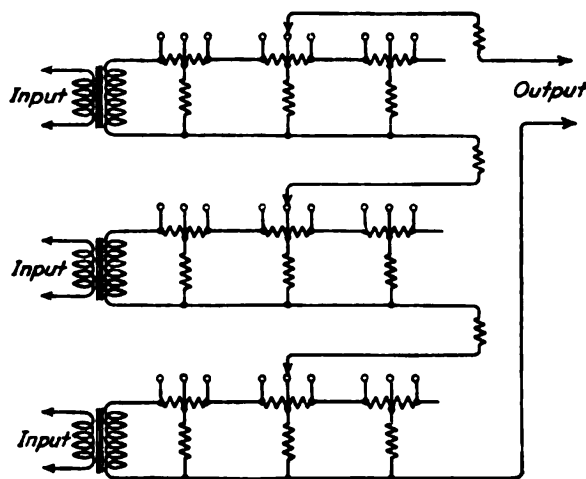


FIG. 11-5.—An improved type of mixer control.

variation of 50 per cent takes place in the output resistance of one control, this position represents only 25 per cent of the mixer impedance, and the total variation will be only one-eighth of the whole, or $12\frac{1}{2}$ per cent. The same condition in a parallel mixer would produce a 20 per cent change in total impedance. If the mixers are working into an inductive load, such as an unloaded input transformer to an amplifier, the advantages of the series type of control will be still more apparent.

In Fig. 11-5 is illustrated a great improvement in mixer controls. Essentially it consists of a number of T pads in series. It will be noted that the taps for the control arm are arranged in such a way that the

device does not always act as a true T pad, also that the pad termination will in most cases be improper. With a multitude of sections, however, the impedance variation caused in this type is too slight to create any audible defect in the mixer action. Such attenuators are known as *ladder networks*. They make exceptionally fine controls and may be used in either series or parallel types of mixers with equal success. As no impedance changes of any note take place in the circuit, condition c in our list is fulfilled, and changing the position of any one control will have no effect upon the output of any other. This effect, when present, is one of the most annoying a mixer can possess.

When high-impedance circuits that are suitable for direct connection into the grid circuit of a tube are to be mixed, a tube mixer offers the best solution to the problem. Stray capacities associated with high-impedance volume controls tend to make the frequency response of their system dependent upon the setting of the control. To avoid this, the units to be mixed have their outputs applied to individual tube inputs, and the outputs of the tubes are then in turn mixed at any desired impedance. Such mixer systems adapt themselves very well to use with commercial equipment which normally utilize high-impedance units. This system also has the advantage that the volume control is working at high program levels. The latter is discussed more fully in the next section.

11.4. Stray Fields and Noises.—In order not to affect the frequency response of the system with which they are being used, the controls should have their resistance units so wound or arranged that they are non-inductive and non-capacitive. Another advantage to be gained by following this practice is the elimination of trouble due to the picking up of stray fields.

At the comparatively high program levels present in the circuit when using carbon microphones or high-level mixing, trouble due to stray fields is not so apt to occur. Their importance increases as the program level in the attenuating unit is decreased.

As an example, suppose a mixer control is used with a condenser microphone having an output of -35 db. A stray field from a power transformer cuts the control and induces into it a 60-cycle signal having a power level of -105 db. The alternating-current signal will be so far below program level as to be unobjectionable. Now, if the set-up is changed to employ velocity microphones, having an output of -100 db, and the same control is used for low-level mixing, the 60-cycle hum in the amplifier output will be only 5 db below the program level. If a completely non-inductive control is substituted the hum will disappear.

When mixers are used to handle directly the low outputs given by dynamic- and velocity-type microphones, the tiny changes in e.m.f. generated by shifting the contacts of the volume controls, due to thermo-couple effects, contact-resistance variations, and so forth, become very important. Because of this fact, there are very few controls available

which will prove satisfactory for use in this manner with these microphones. Those which may be used are very carefully designed and built, and are necessarily expensive.

In order to keep controls as noiseless as possible they must be kept free from dust and dirt, cleaned frequently with carbon tetrachloride, and protected from oxidation by a thin coating of watch oil or vaseline. Some types of contact noises are caused by the speed with which the arm leaves the stud. If the control employs a detent (a device for semi-permanently locking the control arm into position over each stud, usually by means of a spring arrangement) this situation can sometimes be improved by its removal. This has the effect of converting the sweep of the control arm from a series of rapid jumps into smooth variations. The average speed of the sweep over the studs is unaffected, but the individual speed of the arm arrival and departure from each stud is considerably lessened.

When high-level mixing is used, the requirements placed on the volume control are much less severe. If the level is always kept at least 40 db higher than the disturbances introduced in the circuit by the control, the performance will be excellent. As this type of mixing requires a separate amplifier for each microphone, its convenience is somewhat offset by its expense. Where expense and maintenance are not items, it is probably the most satisfactory system.

In any circuit employing very high gains, such as a studio amplifier for use with dynamic microphones (120-db gain), very small disturbances at the input become very objectionable. Thus it is found in practice that under certain conditions, though thoroughly shielded, the cables running from the dynamic microphones to the mixer pick up static charges. If low-level mixing is employed, with the microphone switch located ahead of the volume control, this static discharge may result in a loud "plop" in the circuit every time a microphone is cut in, even though the mixer-gain control is in the OFF position.

There are three fundamental ways of avoiding these disturbances, the first and simplest method being not to use a switch to break the microphone circuit, but to turn it off and on using only the mixer control. Aside from the technical aspect, this method has much to recommend it and is often found in practice. Its great advantage is in the operating routine. It is impossible to turn a microphone on without fading it in. Thus, if mistakes are made and the microphone is turned on a moment too late, the performer having already started, the mistake will not be nearly so noticeable as it would be if a switch were thrown in, as the change will not take place instantly but will occur in a more gradual and less attention-compelling manner.

The second method is to use a switch which automatically grounds both sides of the microphone cable when it is cut out of the circuit. If the mixer is kept at ground potential as well, no static discharge can take place when the microphone is again connected to it.

The third method is to employ high-level mixing and locate the switches in the output of the individual microphone amplifiers. In this position the seriousness

of the discharge is minimized because the program has been raised, and because the amplifier is usually located near the mixer and the leads between the two will be short.

There is another possibility for disturbance in the circuit under these conditions. If the primary of the amplifier-output transformer is above ground potential, and the static shielding between windings is not perfect, a static discharge and consequent pop will occur every time the secondary is switched into the mixer circuit. This may sometimes be avoided by parallel feeding the transformer and grounding the primary, or by employing a switching device, such as already described, which keeps the secondary at ground potential. The latter method is not always permanently satisfactory, owing to the difficulty of maintaining fine contact adjustments.

11.5. Insertion Loss.¹—The insertion loss caused by any item in a circuit is the loss introduced in the circuit by the use of that particular item. For example, if a variable pad (in this example a mixer) is introduced into a circuit, and this pad causes a loss of say 2 db, this loss is referred to as the minimum *insertion loss* of the pad.

Perhaps the best manner in which this condition may be fundamentally illustrated is to break down the component parts of a mixer and its associated circuits into their equivalent fundamental circuits. Let us visualize a mixer unit as a *T*-type pad, as in Fig. 11-6(a). A microphone is connected across input of the pad (Z_1), and the load is connected across the output (Z_2). This load Z_2 represents the primary winding of the amplifier input transformer in series with a number of series pads, as in Fig. 11-3(d), which represents a number of additional microphone pads in the circuit. If we take, for example, a four-microphone mixer circuit (including the microphone and amplifier input transformer) and break it down into its fundamental circuit equivalents, we shall find it to appear as follows:

The microphone is visualized as an alternating-current generator looking into its mixer, which is represented for simplicity as a variable *T*-type pad. The output of the pad is visualized as looking into a load consisting of three resistances and an inductance connected in series. The resistances represent the three other microphone mixer pads and the inductance the primary winding of the amplifier input transformer. Now, if we assume the microphones and the pads to have a resistance of 50 ohms each, and the amplifier input transformer to have a resistance of 200 ohms, we have a picture of a simple electrical circuit equivalent. In other words, we picture a load of 350 ohms tied across the output of the variable *T* pad as shown in diagram (b) of Fig. 11-6.

Now, if we desire to compute the minimum insertion loss of such a mixer, we must first consider the loss of the individual pad. Suppose this loss to be 2 db. (It will depend upon the type of pad used and the tolerances within which the impedances must be maintained.) The microphone then feeds power to the input of the pad, which, in turn, feeds this power (less 2 db loss) to the three pads and the transformer primary which appear across its output.

¹ Readers unfamiliar with pad calculations should study Sec. 11.22 before this section.

We are interested, however, in determining the loss of power by the time it reaches the mixer termination. The power output leaving the microphone pad under consideration is divided between the other pads and the load. Taking 0 db as our primary source and calculating the power actually delivered to the load, we get a resultant of -8 db. Since 2 db of this loss has been occasioned by the insertion loss of

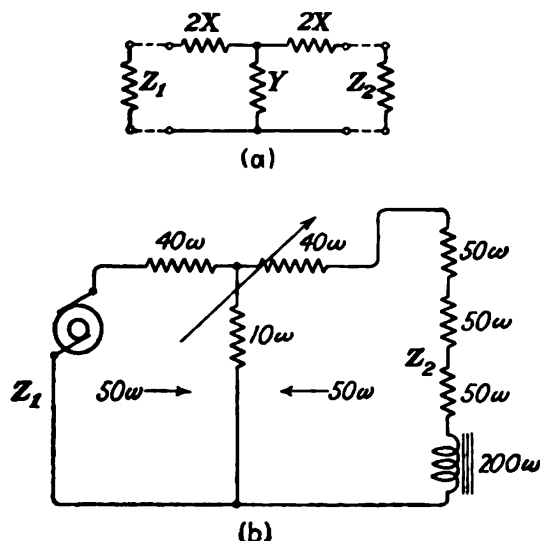


FIG. 11-6.—Diagram to illustrate insertion loss.

the individual attenuator, 6 db is lost in the additional pads making up the mixing circuit. Thus the insertion of the mixer circuit in the network has caused an additional loss of 6 db, and consequently the overall insertion loss of the mixer is 8 db.

11.6. Adjunct (NEMO) and Pickup Mixing.—The program fed into the mixer does not always come directly from a microphone but may be fed in from a phonograph pickup, or from a remote point by telephone line. In the former method the output impedance of the pickup head must be matched to the input impedance of the mixer, usually by means of an impedance matching transformer, or, if there is ample output, by means of an impedance-changing attenuation network. In any event, the output of the pickup should be attenuated to approximate that from the microphone before being introduced into the mixer.

The impedance of a telephone line is generally taken to be 500 ohms. Before connecting it to the mixer it should be passed through a repeat coil designed to terminate it and which is provided with an efficient electrostatic shield between its windings. The output of this coil should be sent through an impedance-changing network in order to match the impedance of the mixer. The attenuation is necessary as the program starts on the line at zero level, and, though this level has been reduced by transmission and equalization losses before it reaches the repeat coil, it is still too high for direct introduction to the mixer circuit.

In practice it is found that for systems designed to handle dynamic microphones, or others having comparable outputs, an H pad (see Sec. 11.22) having an attenuation of about 40 db works well.

The proper termination of remote lines will be discussed in detail under Equalizers and Equalizing in Sec. 11.20.

After these modifications of their outputs have been made, the program from either the remote-control point (adjunct) or the phonograph pickup may be handled by the mixer in exactly the same manner as the output of a microphone.

III. AMPLIFIER CONSIDERATIONS

11.7. Special Precautions against Disturbances.—Modern studio-amplification systems are designed to work with dynamic, velocity-type, and crystal microphones. These microphones have a very minute output and require tremendous amplification following them. With the introduction of such equipment many problems which are of a minor nature when encountered in the comparatively low-gain amplifiers following a carbon or condenser-type microphone now become of major importance.

When it is realized that the power delivered by the microphone to the input of the amplification system may be less than 6×10^{-13} watt, and that any power level impressed upon that input may, by the time it leaves the transmitter, be amplified 10^{13} times, it becomes apparent that even extremely small disturbances in the input circuits of the system will be of a magnitude comparable to the program level and be amplified to about the same extent. It follows then that every precaution must be employed to keep such disturbances from entering the circuit.

To prevent the picking up of stray electrostatic and magnetic fields by the microphone cable, it must be thoroughly shielded. The connecting plugs and sockets at the cable ends are also of importance. Their construction must be such as to insure absolute and firm contact at all times as even the slightest variation in contact resistance will produce serious noises in the circuit.

It is desirable to keep the direct-current input resistance of a high-gain amplifier as low as possible because of the thermal-agitation noise induced by whatever conductor is across its input. At ordinary temperatures and without the application of any external e.m.f., the electrons in a conductor are moving at random. When the e.m.f.s. so produced across the conductor are averaged over a relatively long period of time, such as a second, the voltages produced by this movement of electrons inside the conductor will balance out to zero as such movement is in random directions.

There are instantaneous differences in voltage, owing to the random movement, produced across the terminals of the conductor. A frequency analysis of such voltages shows that practically every frequency conceivable is present. Thus, if the input terminals of a very high-gain amplifier are across this conductor the voltages produced by the random movement of electrons in the conductor are sufficient to produce appreciable output, this output will be in the form of a hissing sound containing

every frequency that the amplifier is capable of producing. The greater the band width passed by the amplifier, the greater the amount of thermal-agitation noise. This noise increases very rapidly as the input resistance is raised, and it is, therefore, desirable to keep this resistance as low as possible.

There is another sound associated mainly with the input tube which creates a noise in the output of the amplifier similar to that of thermal agitation. This is called the *shot effect* of the tube and is due to the fact that electrons are not arriving at the plate in a perfectly steady stream but in bunches at a random frequency.

If the input to the tube is low, the changes in plate current produced by the signal may not be high enough in volume to cover this noise. Thus, the input tube is the most critical as to this effect. Tubes of the same type vary greatly in their shot effect, and, if this is a critical factor in the amplifier involved, the input tube should be chosen by trial from among a number of different types. The situation is sometimes helped by running the filament current of the input tube above its normal rating, which insures a plenitude of electrons from its cathode and tends to give a more even arrival of electrons at the plate.

Carbon resistors contribute a similar noise, owing to their basic structure, and should never be used at points carrying a low program level. The noise generated by such resistors increases rapidly with the value of the resistor.

The choice of input tubes in the amplification system is very limited as they must be especially quiet in operation. Most so-called *non-microphonic* tubes fail to justify that appellation or to prove satisfactory under such stringent requirements. In order to protect them from mechanically transmitted shock the tubes are mounted in cushioned sockets. If a loud-speaker is operated near by, it is sometimes necessary to insulate the first tubes from acoustical shock by surrounding them with a blanket of cotton batting. If this is not done, the acoustical feedback from the loud-speaker may set the tube vibrating at its mechanically resonant frequency. This displaces the tube elements changing their spacing at the same frequency. The change in spacing will, of course, result in corresponding variations in plate current. These are amplified and impressed upon the loud-speaker from which they issue as sound waves and reinforce the vibration of the tube already taking place. In this way a note may be built up to great volumes in the same way that a microphonic detector tube subject to vibration from a loud-speaker sometimes causes a radio set to "howl."

If snap switches or gain controls employing detents are mounted on the same rack as the input amplifiers, the vibration they occasion may prove objectionable. This sometimes necessitates the removal of the detent from the control. When alternating current is used to heat

the emitter (cathode), the problem of preventing hum from entering the circuit is very difficult. This problem will be discussed in detail later in this chapter.

The tube sockets too are very important, for, if the contacts are not firm at all times, or if they tend to oxidize, troublesome noises are introduced into the system. They should be so constructed that, when the tube is inserted, the prongs "wipe" the contact arms, insuring a clean connection between the two. To prevent oxidation, gold-plated contacts are sometimes provided on both socket and tube.

Any disturbance introduced by the input transformer is also greatly amplified. Thus, due to the movement of core laminations, we find microphonics present in transformers. These may cause serious disturbances if the core is subject to vibration or shock. Much more important, however, is the picking up of stray alternating-current fields. To avoid this the transformer inductance is kept as low as possible, and individual magnetic shields of heavy permalloy or soft iron are employed to enclose each unit. Sometimes the transformers and choke coils in the apparatus are oriented for least coupling to the field, wherefore their arrangement in the amplifier should not be disturbed by the operator without due forethought. The low-level (input) amplifiers are mounted as far away from any alternating-current field as possible. This source of hum is perhaps the most difficult of all to avoid.

No shielding can be perfect, thus added precautions must be taken to prevent entry of undesired currents through input lines such as microphone cables.

Whenever possible, the input transformer is center-tapped and this point is grounded. This allows any currents induced into the line to flow through the primary windings to ground in such a way as to neutralize themselves.

It is important then to keep the resistance of each conductor in the cable of any transmission line at the same value. If the line is unbalanced, that is, if the conductor resistance is not equal, the induced currents will be unequal and will fail to balance out. It is for this reason that any network inserted in such a circuit should be of symmetrical construction, presenting the same resistance to each leg of the cable. How this is accomplished is taken up under Attenuation Networks, Sec. 11.22.

If the microphones are used in a mixing circuit it is not always possible to ground the center tap of the amplifier input transformer. The legs of the circuit may not be balanced to ground, and the effect of any currents induced into the individual lines may be increased instead of diminished.

Some of the methods used to eliminate disturbances, due to electrostatic fields and currents, have been taken up in Sec. 11.4. In the amplifier itself, any transformer connected to a line, subject to such

disturbances, should have an electrostatic shield of copper between its windings.

On dry, cold days, especially if the studios employ heavy carpets, persons may easily pick up and store large static charges, caused by friction of their feet with the floor. When they approach a grounded object or another large body they are apt to lose these charges in the form of sparks. Such discharges release a large amount of radiated energy. Hence, when using amplifiers with gains of 100 db or more, it is not unusual to find that the mere spark between two people in the studio or control room, though they are physically separated from any apparatus, produces audible clicks and plops in the equipment.

To minimize the effect of radio-frequency discharges on the apparatus, it must be most thoroughly shielded, and, in order to prevent radio-frequency-detector action, the first few tubes in the circuit must be capable of operating linearly over a much greater extent of their curve than is employed by the program. Even with these precautions, if the discharges are severe, it may prove almost impossible to minimize their effects sufficiently.

The higher the extent of the frequency range reproduced, the more natural and lifelike will be the reproduction. Modern broadcast stations faithfully transmit frequencies up to 10,000 cycles, and newer installations have equipment capable of reproducing up to 15,000 cycles.

11.8. Harmonic and Amplitude Distortion.—In addition to the localized distortion sometimes caused in audio amplifiers (see Sec. 5.9), there are other types of distortion likely to be encountered in studio systems owing to the wide range of frequencies covered by these equipments. As the frequency range of the apparatus is extended many new problems arise. One of these is harmonic distortion originating in component parts of the system. By way of illustration, let us study the following:

Suppose a microphone capable of responding to frequencies from 60 to 6,000 cycles is used with equipment cutting off at 5,000 cycles. The quality of reproduction would be considered as being good, and it would be pleasant to listen to. The microphone has strong harmonic components, however, at fundamental frequencies higher than 3,000 cycles, but, as its lowest harmonic will then be 6,000 cycles, these strong-harmonic frequencies will not be reproduced by the amplifier (it cuts off at 5,000 cycles) and will not appear in the output. This same microphone when connected to an amplifier which is efficient up to 15,000 cycles might give very unpleasant reproduction, as with such equipments these harmonic frequencies, ranging from 6,000 to 15,000 cycles, will be amplified to their true extent making audible those frequencies (harmonics) which heretofore had been filtered out by the poorer amplifier.

In the same manner, harmonic distortion occasioned by tube overload in amplifiers is not nearly so objectionable with equipment of restricted frequency range as it is in apparatus of higher fidelity characteristics.

To understand the importance of harmonic addition or suppression in broadcasting, the student must have some fundamental knowledge of the

reproduction of musical tones. Suppose that we hear middle C played upon a violin, a flute, and a French horn, successively. One recognizes it as the same note in each instance, and this is because that particular note has a frequency of 256 cycles per second regardless of its source. Yet there is no difficulty in telling which instrument is playing at any time. The difference in the quality or timbre of the note lies entirely in the number of harmonics present and their proportion to the fundamental tone as shown in Table XIA. It is this that enables us to distinguish between the instruments. Thus, if the harmonic content of a note is altered in any way, it changes the timbre of the tone.

The difference in the tone achieved by a great violinist and that of a sawing fiddle player lies wholly in the different harmonic contents of the same fundamental note. If the instrument adds or subtracts harmonics it is then impossible faithfully to reproduce tone values. In this way a naturally pleasing note may be given harsh and unpleasant characteristics when reproduced. Distortion of this type must be guarded against very carefully in amplifying apparatus, as it does not show up to any extent in the usual frequency-response curve. When present to only a small extent, harmonic distortion is not particularly noticeable to the ear

TABLE XIA.—RELATIVE STRENGTH OF PRIME NOTE AND HARMONIC COMPONENTS

	Violin; energy, per cent	Flute; energy, per cent	French horn; energy, per cent	Violin note reproduced in ordinary tele- phone receiver (note distor- tion); energy, per cent
Prime*.....	60	13	2	8
Harmonics:				
Second.....	8	40	10	50
Third.....	20	10	50	8
Fourth.....	10	20	15	2
Fifth.....	2	5	5	
Sixth.....	..	2	2	
Total.....	100	90	84	68

* Middle C.

unless a direct comparison can be made between the original and transmitted sounds, or unless one is very familiar with the tones involved. If direct comparison is made between apparatus having some harmonic addition present and other equipment free from this defect, the output of the latter will appear to be clearer and cleaner than the former.

Tube Harmonics.—Let us consider harmonic distortion which is sometimes generated by the tube itself. Any periodically recurring wave shape, which is not a sine wave, can by analysis be shown to be made up

of a number of sine waves having different amplitudes and frequencies. This is an important statement to the student, and he should regard it as such. If, then, by passing a sine wave through any piece of equipment we even slightly alter its shape so that the upper and lower half cycles do not correspond in amplitude, the wave so produced will no longer be a single frequency but will be made up of the original frequency and other added harmonic frequencies of different amplitudes. The greater the distortion of the wave shape, the greater the percentage of harmonics present.

If the grid-voltage swing of a tube is limited so that the plate current is never driven off the straight-line portion of the characteristic curve (see

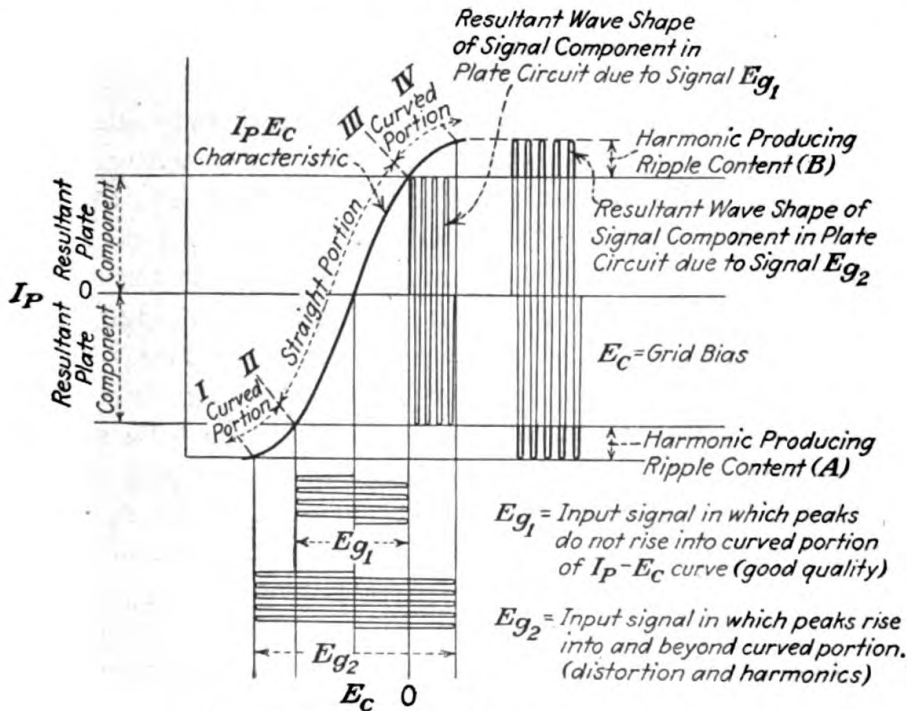


FIG. 11-7.—Analysis of harmonic distortion.

Fig. 11-7), the resultant change in plate current will be an exact reproduction, in so far as wave shape is concerned, of the incoming signal on the grid. Under such conditions no frequencies that are not present in the input are added to the output, and the tube is free from amplitude distortion.

By inspection of the curves it will be noted that if the grid voltage E_{g2} swings the plate current down to such an extent that the curved portion of the characteristic is involved, the resultant plate current I_p over this part of the curve (points I and II) will be *greater* than if it were a straight line between these points. Such a grid swing will also drive the plate current I_p up on the upper curve at the next half-cycle (points III and IV). Here it will be noted that the resultant plate current I_p will be *less* than would be given by a straight line up to this point IV.

Hence the peak of the negative swing will be amplified to a different extent from that of the positive swing, resulting in a distortion of the wave shape and the addition of harmonic frequencies which that entails.

In practice such distortion can be shown visually by the insertion of a direct-current meter in the plate circuit of the tube involved. A visual indication is much more reliable in every respect than an aural one, as with the former the personal element does not enter into the calculation to any extent, nor is the ear capable of giving accurate quantitative measurements.

The average value of a recurring wave shape whose half-cycles match each other is zero, that is, the mathematical addition of the positive and negative halves of the cycles gives zero as their sum. The average value of any recurring wave shape whose half-cycles do not match each other in amplitude must be greater or less than zero.

A direct-current ammeter of the usual type reads only average values of current. Suppose such a meter is inserted in the plate circuit of a tube. If a signal is introduced to the grid of the tube and the amplified output is free from harmonic distortion, the average value of the plate-current change produced by the incoming signal will be zero. Thus the average value of the plate current is the same whether the signal is present or not, and, as the meter in the circuit reads average values, its indication will remain unchanged, assuming class A amplifier operation.

If a sinusoidal signal is injected into the grid of a tube which is not operating linearly and is introducing harmonics, the average value of the audio-frequency component in the plate current will be greater or less than zero. It will then add or subtract from the meter reading obtained when there is no signal present. If the signal is not steady but varies in level as does a program, the meter reading will either dip or rise at the high-level peaks. Hence, a direct-current meter is usually kept in critical circuits in order that the presence of distortion may be immediately indicated. The remedy is, of course, to reduce the overload condition by reducing the signal input.

11.9. Advantages of Low-gain Amplifiers.—As the number of stages in an amplifier is increased, it becomes more and more difficult to secure stable operation. Owing to undesired energy being fed back from output to input, through coupling of the transformer fields or otherwise, the circuit has a tendency to go into oscillation. The precautions necessary to prevent such action become prohibitively expensive and awkward when more than two successive steps of high-gain amplification are employed. With a low gain per stage, stable amplifiers having three or four stages may be built. For this reason, when it is necessary to construct reproducing systems having great overall amplification, instead of concentrating the entire gain in one amplifier, it is split up over several succeeding units of individually low-gain amplifiers of high stability.

These are placed sufficiently far from each other to avoid undesirable coupling between them.

This system has the added advantage that attenuation networks or gain controls can be inserted between the units to cut down the overall amplification. These, by increasing the loss between the individual amplifiers, decrease the possibility of sufficient feedback between them to start the system oscillating.

If the individual units are run from the same power supply, it is necessary to provide adequate filtering in each amplifier to prevent audio-frequency variations from entering into the supply circuit and so affecting the stability of the system, or causing cross talk in other units energized by the same power source.

11.10. Types of Broadcast Amplifiers.—In the earliest days, broadcast amplifiers were nearly all impedance coupled. Then as transformers of high quality became available, they became almost 100 per cent transformer coupled. With the rapid strides in high-gain tube development, in the last decade, they have become in the main resistance coupled, with input and output transformers to give them the desired input and output impedance.

It is now a relatively simple affair to achieve an overall frequency response of 20 to 15,000 cycles. However, this does not mean that all the problems involved and discussed in high-gain amplifiers may not still be present.

11.11. Plate and Grid Filtering.—When using plate-current return to cathode in order to bias a tube, it is important to prevent variations in this plate current from being applied to the grid. If the grid bias is secured by bringing the grid return to the ground side of the biasing resistance, without providing any kind of a filter circuit, such as a condenser across this resistance, the variations in plate current produced by the signal will cause corresponding variations in grid voltage, which will be out of phase with the signal originally impressed on the grid. This will tend to neutralize the effects of the original signal by introducing degeneration into the circuit. Also if there is hum in the plate current, because of a ripple from an insufficiently filtered power supply, this hum voltage will also be impressed by the biasing resistance upon the grid of the tube and will be amplified by it. In order to avoid these effects, a condenser with a reactance low enough to act as a short circuit to the lowest frequency involved (rule of thumb is one-tenth the impedance of the by-passed part) may be placed across the biasing resistance. However, when the value of the resistor is low, and low-frequency components are involved, the capacity value necessary to do a good job may reach fantastic proportions. The efficiency of the circuit may be raised very greatly by the addition of a resistor in the grid circuit in the position shown in Fig. 11-8(a). This resistance is made as high in value as possible without running into the

If low-level mixing is used, the main gain control is usually placed between the low- and high-level amplifiers. This position has two advantages. (1) Because the unit is working at comparatively high program levels, it will be quiet in operation; and (2) because of its position, it decreases the overall amplification between input and output of the amplifier system and thus vastly increases the stability.

In order not to disturb the impedance relations in the circuit, such gain controls are made up of variable, constant-impedance attenuation networks, on the order of those illustrated in Figs. 11-3(c) and (d) and 11-5. They must be non-inductively wound so that they will not be affected by stray fields. Their capacity and unbalance to ground should be kept low, so that the frequency response of the system is unaffected by their use.

If the gain control employs a detent and is mounted on the same rack as the first amplifier, trouble may be encountered through tube microphonics occasioned when the control is moved. This may be helped by removing the detent, but a far more convenient method is to mount all switches and controls on a turret apart from the amplifier. This turret,

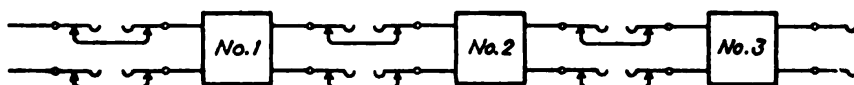


FIG. 11-9.—Method of connecting units of studio amplifiers together through jacks.

which also carries the volume indicator, is mounted on a desk so placed that the operator is looking into the studio through the soundproof plate-glass windows provided for this purpose.

The use of potentiometers to act as volume controls, by varying the voltage input from the secondary of the transformer to the grid of the tube, is sometimes encountered. This system is becoming obsolete, as the control cannot be made remote to the amplifier owing to the high impedance of the leads and because it has been found detrimental to good high-frequency response.

11.13. Jack Circuits.—To insure maximum flexibility, and to enable service to be resumed with minimum delay in case of breakdown in any unit, all the inputs and outputs of the component parts of the reproducing system are brought out to jacks. They are normally connected together at the jack contacts as illustrated in Fig. 11-9.

Thus in the circuit shown, if unit 2 should prove defective, it may be bridged out of circuit by inserting a patch cord into the output jack of unit 1 and into the input jack of unit 3. The action of the plug inserted into the jack is to lift automatically the jack arm and break the contact with unit 2, removing it from the circuit entirely as shown in Fig. 11-10. In a like manner, duplicate pieces of equipment may be brought out to jacks, and if trouble occurs, all that is necessary to substitute workable

units into the circuit and to remove the defective part is a pair of patch cords.

As all equipment is in this way brought out to a central panel, long interconnecting leads are necessary. In order to minimize the effect of their distributed capacity upon the frequency response, the input and output impedance of all units is kept at a low value. This also helps to prevent undue losses to ground through stray capacities and stray pickups due to the fields about the cables and patch cords. Usual terminal impedances are 50, 200, 250, and 500 ohms.

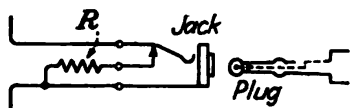


FIG. 11-10.—Closed circuit jack and plug.

In order to eliminate cross talk and pickup by the circuit, all exposed wiring is shielded. It is of importance first to band together all the individual conductor shields and then to ground these as a unit at as many points as is convenient. If this is not done, any differences in potentials to ground of adjoining shields are apt to cause trouble when using the extremely high gain encountered with modern equipment.

11.14. Reducing Hum Level.—As the fields about the wires carrying the alternating-current filament supply may induce hum into the system, every precaution must be taken to keep its value low and to keep it as far as possible from the equipment. If the two conductors carrying the current could occupy the same point in space at the same time, the fields about the conductors would completely neutralize each other as the currents in the wires are equal and flow in opposite directions. This hypothesis is manifestly impossible, but it is approximated by running the wires as closely together as possible, that is, by twisting them. As the fields are not completely neutralized the alternating-current wiring is enclosed by a heavy shield, and is carried on the opposite side of the rack from the program circuits.

The filament transformers and high-voltage rectifier are mounted at the bottom of the rack and a heavy magnetic shield interposed between them and the rest of the apparatus. The student must remember that, contrary to the general impression, a perfect shield is possible only in theory. It is for this reason that the low-level input amplifier is kept at the extreme top of the assembly, away from the fields of the power-transformer.

When components are mounted in a console, the power supply is usually mounted elsewhere and at a distance, thereby eliminating the effects of any fields that might be set up by the power equipment.

11.15. General Considerations.—The greatest step forward in program-transmission systems was the advent of equipment capable of being operated directly from the alternating-current power line. With such equipment, each control room and its adjacent studio installation may be made a complete self-contained and independent unit. Elaborate

and costly wiring to a centrally located battery supply is eliminated, as are the items of maintenance, expense, and the additional floor space which batteries entail. The use of such alternating-current systems is now almost universal, and battery systems are only encountered in older installations.

A complete control-room system capable of handling two studios and an announcing position as well as incoming program circuits and transmitter feed is illustrated in Fig. 11-2. It is typical of the type of equipment mentioned here. The program usually leaves the individual control room using such equipment at a level of 0 db, ready to be impressed directly upon the transmission line. In master-control-room systems, switching may be done without any further amplification.

The use of such equipment has materially reduced the expense of installation as it comes factory wired and ready to set on the floor in the rack models and on a table in console models. Relatively few connections need be made on the job and these are to terminal strips. Thus, the salvage value of the equipment is high as it can be moved from place to place without the necessity of rewiring the unit itself.

IV. PROGRAM TRANSMISSION

11.16. Speech-input Equipment. *a. General Description.*—The equipment to be described in this section is the Western Electric No. 23C speech input equipment. This equipment is an alternating-current-operated amplifier assembly capable of providing speech-input facilities for two studios in small radio-broadcasting systems. Where more studios are required, it is adaptable for use in conjunction with other equipments of the same type, the outputs of which may be coordinated in a master control room. In addition, it will prove valuable for use at radio-transmitter locations where studio facilities are required, and because of its compact form and simplicity of installation, will find use at semipermanent remote pickup points.

The equipment has a net gain of approximately 96 db. It operates from a 105–125-volt 50–60-cycle alternating-current supply. As supplied from the factory, the power transformer is connected for operation from an alternating-current supply of 120 volts nominal voltage. The power consumption under these conditions is 81 watts at 115 volts, 87 watts at 120 volts, and 96 watts at 125 volts.

The following accessory parts are required for the operation of this equipment:

- 7 RCA or equivalent type 1603 vacuum tubes.
- 2 RCA or equivalent type 42 vacuum tubes.
- 1 RCA or equivalent type 83V vacuum tube.

A 12-volt direct-current source of power, capable of supplying approximately 0.25 amp., is required for the operation of the loud-speaker cutoff

relays and the signal lamp. A Western Electric KS-7593 rectifier is recommended for this purpose; this rectifier, however, is not furnished as part of the equipment and must be purchased separately.

The component parts of the No. 23C speech-input equipment are assembled on a metal chassis. The assembled equipment is protected by three covers which also provide shielding between the various parts. The chassis and covers are finished in dark-gray crinkled lacquer. Two photo-etched control panels finished in black are located on the front. The arrangement of the controls on these panels is shown in Fig. 11-11. The inclined panel, located in the center, contains the microphone, audition-break, monitor transfer, and output switching keys, the program-line mixing control, and the monitor gain control. The vertical panel extending entirely across the lower front contains the program-line keys, microphone-mixing potentiometers, master-gain control, head-

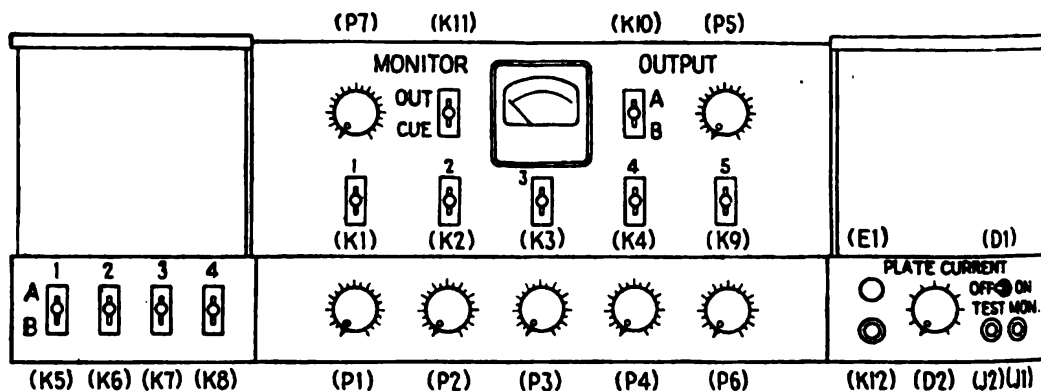


FIG. 11-11.—Western Electric 23C Speech-input control console.

phone-monitoring jack, plate-current switch and jack, power switch, and signal key and lamp.

The No. 23C speech-input equipment contains four input switching circuits each with premixing amplifiers for microphones or other program sources of comparable level, and one input circuit for a 500- or 600-ohm incoming program line, all of which are combined in a five-channel mixer. The No. 23C speech-input equipment may be used with either 30- or 250-ohm microphones. Connections for the desired impedance must be made at time of installation. The equipment is designed to operate into either one of two 500- or 600-ohm output circuits. It also includes a monitoring amplifier and an indirectly lighted volume indicator, with provision for an extension meter. The overall schematic diagram is shown in Fig. 11-12. Numbers on terminals and apparatus, are for reference only and do not appear on the equipment. Vacuum-tube socket terminals are identified by numbers on the apparatus itself.

A simplified type of wiring diagram is used here in order to avoid confusion which might arise from the maze of lines required to represent

actual wires in a conventional-type diagram. Apparatus components are shown in their approximate locations, and designations and terminal numbers have been assigned for reference purposes.

The microphone input circuits consist of the switching keys, K_1 , K_2 , K_3 , K_4 , and K_9 (Fig. 11-11), and four single-stage premixing amplifiers which terminate at the mixing potentiometers. The microphone switching keys K_1 to K_4 provide for the selection of any of four microphones or other equivalent program sources in each of two studies and key K_9 for connecting an announcing or "talk-back" microphone in the control room to premixing amplifier 4, in place of the microphones associated with K_4 . The program-line input circuit consists of the keys K_5 , K_6 , K_7 , and K_8 which are arranged to connect any one of four incoming program lines either to a mixing potentiometer or to the monitor amplifier for preliminary monitoring.

The mixing potentiometers, designated P_1 to P_5 , are arranged in a parallel circuit, the output of which is amplified through a single-stage amplifier terminated in the master gain control P_6 ; this is followed by two additional stages of amplification. The output of the amplifier system operates into a line isolation pad composed of resistances $R_{38.1-2}$, R_{39} , $R_{40.1-2}$, R_{55} , and R_{56} . The volume indicator is bridged across the input of the line pad and is calibrated to indicate a fixed level into the pad. The equipment is normally supplied for operation at the maximum output level of +18 VU. For operation at other output levels, the resistances $R_{38.1-2}$, R_{39} , and $R_{40.1-2}$ must be replaced by other resistances of the proper values. The output switching key K_{10} connects the output of the line pad to either of two outgoing lines. In the center or intermediate position, this key terminates the pad in 600 ohms.

The input of the monitoring amplifier is connected to the monitor transfer key designated K_{11} , which can be used to bridge the monitor amplifier across the output of the line amplifier, or to connect it to an incoming program circuit or other external circuit to be monitored. The output circuit of the monitor amplifier is arranged to supply a total of three 250-ohm dynamic-type monitoring loud-speakers. The loud-speaker circuits are provided with cutoff relays S_1 , S_2 , and S_3 , which substitute 250-ohm resistance loads when the loud-speakers are not in use. The connections to the windings of the relays and the control circuits of the microphone keys K_1 , K_2 , K_3 , K_4 , and K_9 are brought out to the same terminal strip so that by strapping the terminals various combinations of operating condition can be obtained. A jack for headphone monitoring is also provided.

Supplementary equipment includes a key and lamp for signalling, a main power switch, and a selector switch and jack arranged to insert an external meter in the cathode circuits of the vacuum tubes for measuring the total space current of each tube.

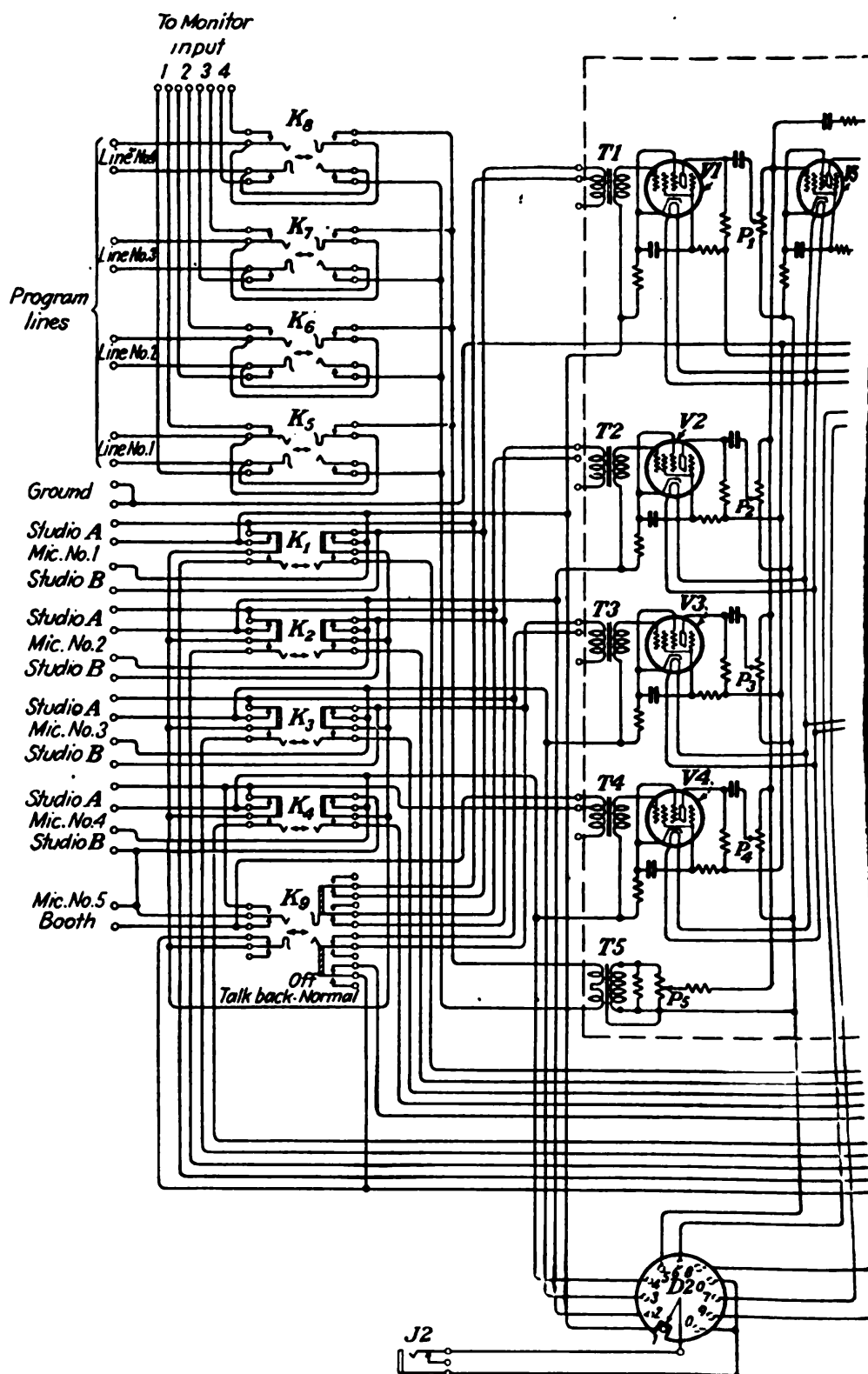
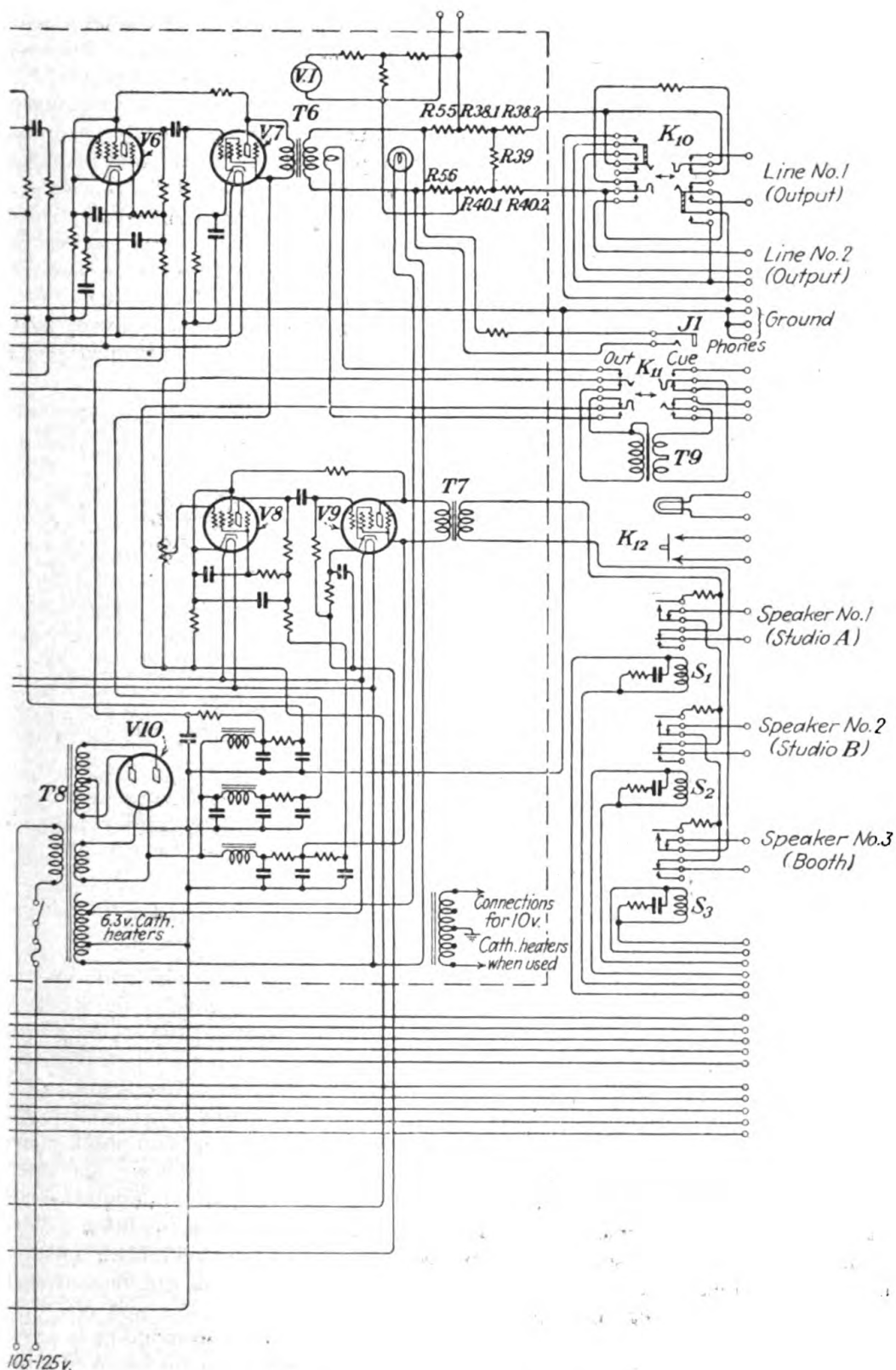


FIG. 11-12.—Western Electric

105-125v.
A.C. Supply

23C Speech Input circuit diagram.

b. Operation.—Figure 11-13 is a simplified block schematic diagram of the No. 23C speech-input equipment as used in a typical installation. Four microphones and a monitoring loud-speaker are shown in each studio and an announcing and talk-back microphone and monitoring loud-speaker in the control room. The equipment is arranged so that the control-room microphone can be used either for local announcements or for talk-back purposes through the studio loud-speaker during rehearsals, and the monitoring amplifier is arranged to monitor upon any of the four incoming program lines. The selection of microphones is controlled by keys K_1 , K_2 , K_3 , K_4 , and K_5 . (In the description that follows, see Figs. 11-11, 11-12, and 11-13.) When studio microphones are in use, key K_5 must be in the DOWN position. Operating K_1 , K_2 , K_3 , or K_4 to the UP position connects the associated microphone in studio A to the premixer amplifying stage and the corresponding potentiometer P_1 , P_2 , P_3 , or P_4 . At the same time, relay S_1 is operated, disconnecting the studio A monitoring loud-speaker and substituting a 250-ohm resistor in its place. Operating a microphone

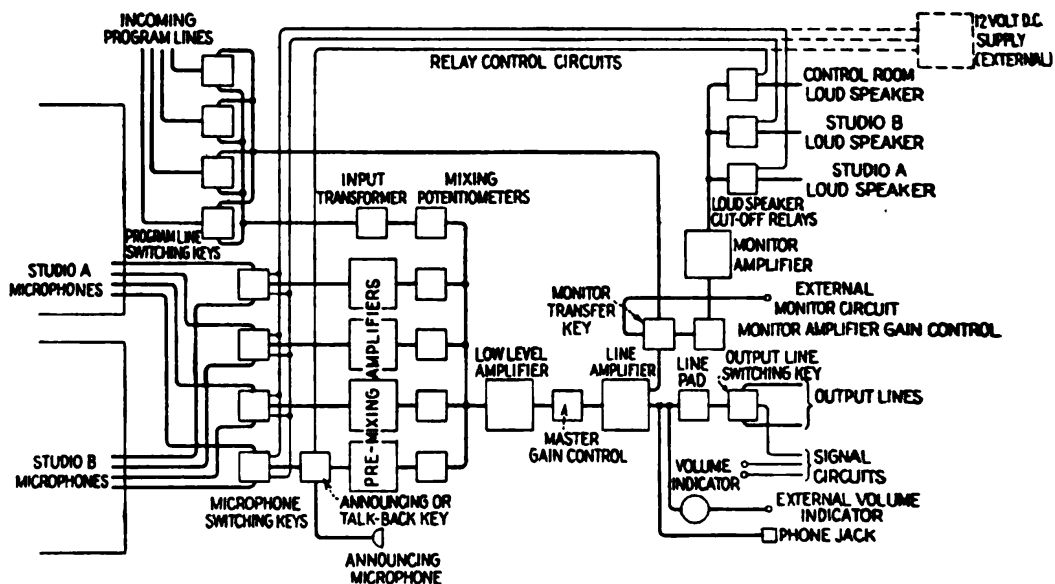


FIG. 11-13.—Western Electric 23C speech-input block diagram.

key to the DOWN position disconnects the studio A microphone and connects the corresponding studio B microphone, operates relay S_2 and disconnects the studio B monitoring loud-speaker. If K_5 is operated to the UP position, the studio microphones are disconnected and the announcing microphone is connected through the associated premixer amplifying stage to P_4 . Relay S_1 is operated, disconnecting the control-room monitoring loud-speaker and S_1 and S_2 are released, placing the studio loud-speakers in service. It is this releasing of the studio loud-speaker cutoff relays that enables the control-room operator to converse with the studios. The intermediate positions of K_1 to K_4 are the OFF positions, and all studio microphones are disconnected. The intermediate position of K_5 is not an operating condition. With K_5 in the intermediate position, the control-room loud-speaker cutoff relay is operated and all microphones with the exception of those associated with K_4 are disconnected.

The selection of program lines is controlled by keys K_6 , K_7 , and K_8 . The operation of any of these keys to the B position connects the corresponding program line through the transformer T_1 to mixing potentiometer P_1 . The operation of a key to the A position connects the corresponding line through the transformer T_1 to the CUE terminals of key K_{11} . If K_{11} is now operated to the CUE position, the monitoring

amplifier is connected to the program line. This arrangement provides a convenient means of observing CUE signals on remote or chain programs. In the intermediate positions of keys K_4 to K_8 , the incoming program lines are disconnected.

The output line is selected by the operation of K_{10} . In the *A* position, output line *A* is connected, in the *B* position, output line *B*. In the intermediate position, the output pad is terminated in a 600-ohm resistance.

The switching of the monitoring amplifier is controlled by K_{11} . When operated to the *OUT* position, this key connects the monitoring amplifier across the output of the line amplifier. In the *CUE* position, and with the proper straps on the terminals, the key connects any incoming program line through T_1 to the monitoring amplifier upon the operation of K_4 , K_6 , K_7 , or K_8 to the *A* position.

In the intermediate position, the monitoring amplifier is connected through T_1 to an additional set of terminals provided for an external circuit on which monitoring is desired.

c. Maintenance.—The equipment is so designed as to require very little maintenance. However, such parts as vacuum tubes and electrolytic condensers will necessarily have a limited life.

It is recommended that a complete spare set of vacuum tubes be kept as follows:

7 RCA or equivalent type 1603 vacuum tubes.

2 RCA or equivalent type 42 vacuum tubes.

1 RCA or equivalent type 83v vacuum tube.

In using the type 1603 vacuum tubes, different tubes may be tried in vacuum-tube sockets V_1 to V_4 to obtain the lowest possible noise level. It is also recommended that several spare fuses be kept on hand.

The electrolytic condensers used in the power supply also have a limited life. Deterioration is indicated by a gradual increase in the hum level of the amplifiers. If this reaches an unsatisfactorily high value, it is suggested that the entire set of electrolytic condensers be replaced.

The gray crinkle finish of the cabinet may be cleaned by wiping with a clean rag moistened with carbon tetrachloride. Scratches and chips in the finish may be repaired by the application of gray enamel to the injured areas. The photo-etched control panels may also be cleaned with carbon tetrachloride.

d. Recommended Accessory Equipment.—The following accessories are recommended for use with the No. 23C speech input equipment.

1 Western Electric No. 1002F headset.

Western Electric dynamic microphones with stands and cords, number as required.

Three 250-ohm monitoring loud-speakers.

1 Western Electric No. 18 type resistance.

2 Western Electric No. 19 type resistances.

Note: These resistances are for use in the output pad if an operating level other than +18 VU is desired.

One 0-2 scale milliammeter.

One 0-50 scale milliammeter.

One 2-conductor cord equipped with Western Electric No. 47A plug or equivalent.

11.17. Remote-control Equipment.—This apparatus is similar to studio equipment except that it is constructed in such a way as to achieve utmost portability. It consists of an amplifier, mixer, and volume indicator and associate essentials. Low-drain tubes are usually used with a dry-battery power supply, although airplane-type light storage batteries are sometimes used for filament supply.

Where power supply from the mains is dependable, alternating-current equipment is usually used. The exact design of remote equipment is highly individual and varies according to the requirements of the station employing it.

Smaller stations, in the interests of economy, do not always send an operator to each remote broadcast. If a certain dance band is to be picked up at regular intervals, an amplifier and microphone are left set up at that point. In order to go on the air the announcer turns on the filament switch and, after making tests with the studio to assure all concerned that the system is functioning, stands by for his cue to proceed with the broadcast. This cue is usually delivered over the talking line, either verbally or by means of signaling with the calling bell. With such a system no volume indicator is required, nor is a mixer usually used.

The equipment must be capable of withstanding great changes in program level without distortion. The output tube should have a maximum undistorted output of at least +14 db, and the gain control should precede the first tube in the amplifier. The output of the amplifier is adjusted so that the program level on the line is not normally higher than necessary to cover line noise. When intelligently used and given adequate maintenance, such set-ups are entirely satisfactory in their results.

A typical portable speech-input equipment is the Western Electric type 22D, which will now be described. The improvements in this equipment over older equipment are:

1. Use of new VU volume-indicator meter.
2. Off position of output line keys equipped to close outgoing program loops so that master control can test the loop resistance prior to program transmission.

a. General Description.—This equipment provides complete pickup facilities for broadcast programs remote from the studio and serves exceptionally well as a permanent set-up in small broadcast studios. It is designed for fast set-up, is simple in operation, and can be handled easily by one man. Examples of the more permanent set-ups are its use to provide emergency facilities, supplementary services, and for service where flexible program-control facilities are required but space is limited. A block diagram of this equipment is shown in Fig. 11-14.

The 22D consists of a combination amplifier-control unit with a carrying case, a rectifier unit for alternating-current operation, and/or a battery rack assembly with a carrying case, together with the necessary interconnecting and power cords. Controls and the volume-indicator meter are on the front panel of the amplifier-control unit. Microphone input receptacles are at the left end, and the output line terminals, monitoring headset jacks, order wire telephone set connections, and power receptacle are at the right end.

Each carrying case is divided into two compartments. One houses the principal unit and the other houses accessories such as microphone, monitoring headsets, spare vacuum tubes, and connecting cords. The entire equipment is compact and light in weight.

The 22D equipment includes a four-channel paralleled mixing circuit, designed to work with 30-ohm dynamic microphones or other 30-ohm sources of comparable level. The output circuit includes line-isolation pads and is designed to work into an imped-

ance of either 150 or 600 ohms, the selection of which is made by means of a screw-driver adjustment. See circuit schematic diagram, Fig. 11-15.

When operated between the impedances mentioned above, namely, 30 and 150 or 600 ohms, the maximum overall net gain of the system approximates 92 db. Normal output levels between +6 and +14 VU can be obtained readily by using the master gain control located between the first and second stages which provides an attenuation up to 45 db and by using the four-channel mixing circuit which is ahead of the amplifier and furnishes an additional attenuation of as much as 45 db.

The frequency characteristic is uniform within ± 1 db, from 30 to 10,000 cycles. The harmonic distortion under normal operating conditions is less than 1 per cent, at

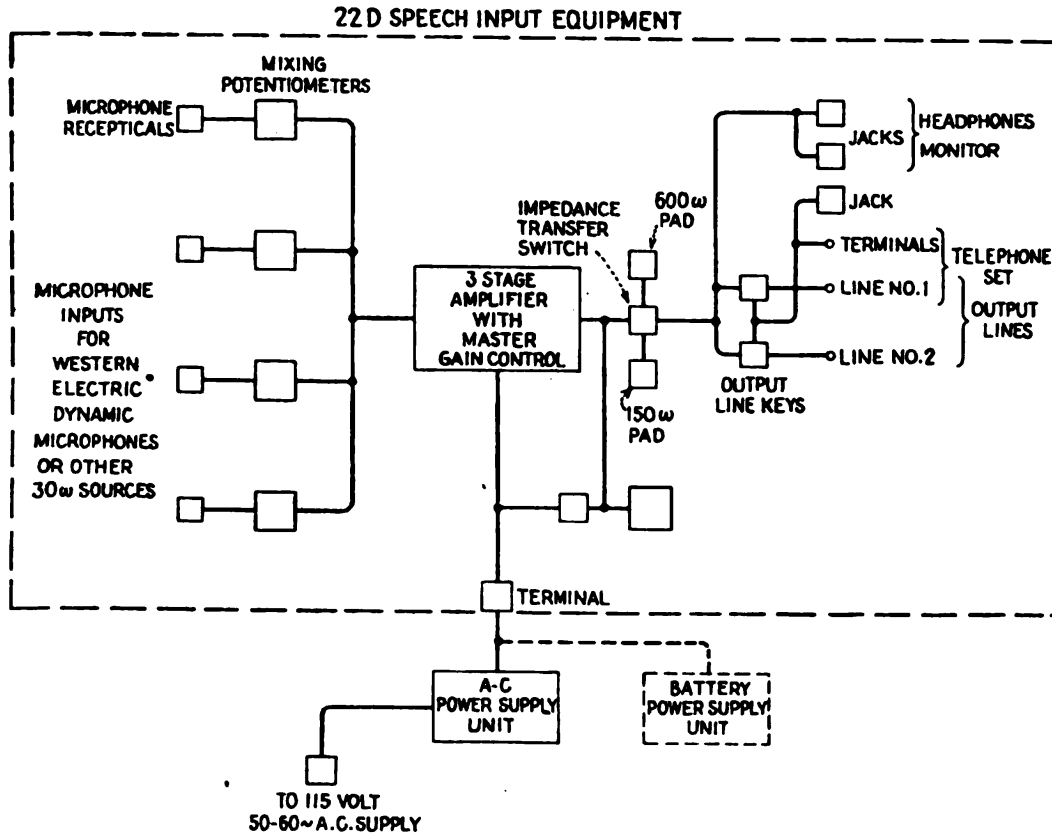


FIG. 11-14.—Western Electric 22D speech-input block diagram.

output levels as high as +18 VU. The noise level of the equipment is 48 db unweighted and 60 db weighted (as the ear would hear it) below normal program level measured at the output.

b. Input and Gain-control Circuits.—The four-channel mixing circuit ahead of the amplifier is designed to work with 30-ohm dynamic microphones or other equivalent sources.

Microphones having an impedance of approximately 250 ohms can be used also, provided an external impedance matching coil such as the Western Electric 172A repeating coil is inserted between the microphone and the mixer. The 172A repeating coil has an impedance ratio of 250:30 ohms and was particularly designed for this purpose. Connections are made to the terminal plate which then is covered by means of a protective cap.

The microphone input circuits are connected through associated mixing potentiometers to the input of the amplifier. Each mixing potentiometer has an OFF position

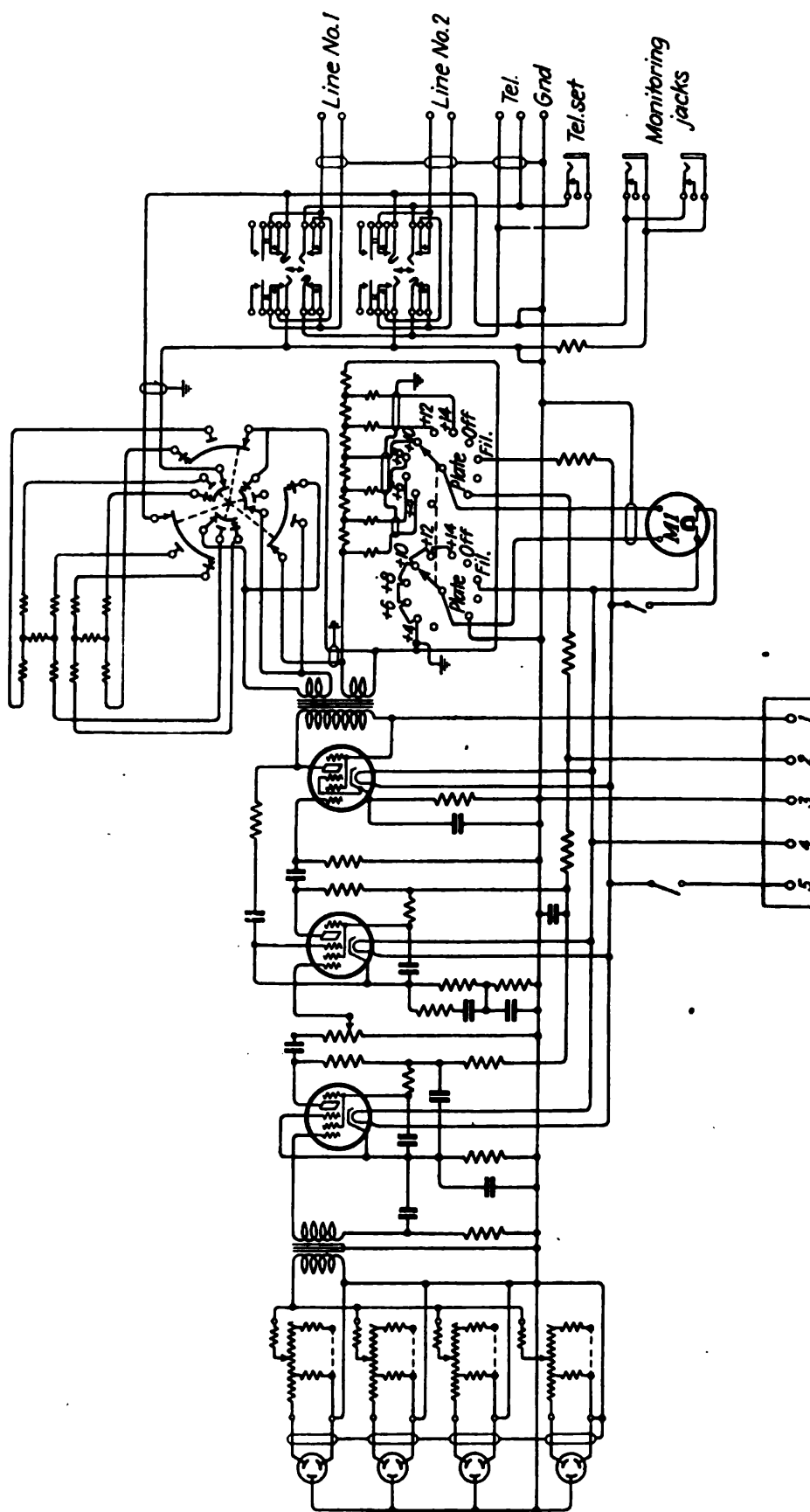


FIG. 11-15.— Western Electric 22D Speech Input circuit diagram.

and a total attenuation of 45 db in 20 steps, the first 12 of which have $1\frac{1}{2}$ -db attenuation each, with the attenuation gradually increasing in the last eight steps to cutoff. The output of the mixing circuits is amplified through a single stage, terminating in the master gain control, which is followed by two additional stages of amplification. The master gain control has 20 steps of attenuation and an off position. The first 17 steps from minimum attenuation have 2 db attenuation each, with increasing attenuation on the last three steps to cutoff.

c. Output Circuit.—Two isolation pads are provided: one to match 150 ohms and the other, 600 ohms. The 600-ohm pad is the standard for use with equalized 600-ohm line circuits. The 150-ohm pad is furnished for use with short, unequalized cable pickup circuits where the resulting impedance mismatch provides a beneficial equalizing effect, which tends to compensate for the frequency transmission characteristics of the line.

There are two lever-type line keys. A program line may be connected to each of these keys through the line binding posts. By throwing either of these keys downward, connection is made between the line associated with that key and the output of the amplifier, thereby allowing program feed to that line or receipt of cue from master control on the monitor headphones. By throwing the key upward, connection is made with the line to the "Tel" jack or the paralleled pair of binding posts located on the end of the unit. In cases of emergency, the program and order wire lines can be immediately interchanged by simply reversing the key positions. When in the normal position, these keys short-circuit the program lines and enable a station operator to make loop tests.

In places where program lines terminate in jacks which accommodate the 47 type plug, a 630 type cord (5 ft. 6 in.) equipped with a 47B plug is recommended. The other end of this cord is terminated with pin terminals which fit under the binding posts. The 630 type cord is supplied only when specifically ordered.

d. Communication Facilities.—When a telephone set, such as the Western Electric 301A, is plugged into the Tel jack by means of a 47 type or similar two-conductor plug or connected with the Tel binding posts, the line can be used for communication with the master control room.

While simultaneous program feed and communication cannot take place over a single line, the key-switching feature—which allows rapid interchange between the line of the telephone set for communication and the amplifier output for program transmission—considerably facilitates operation where only one line is available to the control point or radio transmitter.

When two lines to the master control are available, one can be used for program feed or receipt of cue preceding transmission and the other for simultaneous communication. With this arrangement, the communication line can be substituted immediately for broadcast by throwing both keys into reverse positions and making a corresponding switch in the master-control room. This rapid interchange feature between the two lines at the remote point provides a necessary safety factor, especially valuable when important programs are being broadcast.

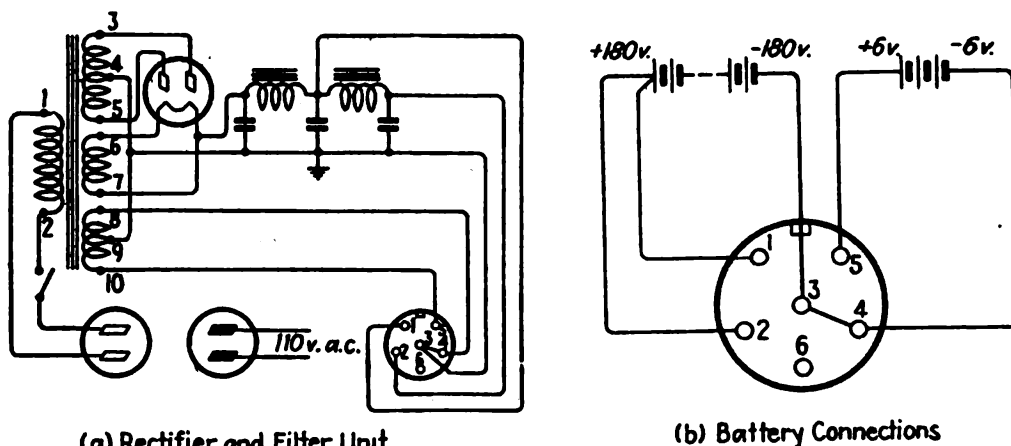
If a telephone set is not readily available, it is possible to carry on communication by using the announcing microphone and the amplifier for outgoing speech and the monitor headset for incoming speech.

e. Monitoring Facilities.—One or two headsets, such as the Western Electric 1002F, may be plugged into the jacks provided to monitor the output of the amplifier. With two separate headsets, the production man, announcer, or guest may listen in with the control man. Where loud-speaker monitoring or feed for the local public-address system is desired, it can be obtained without disturbing the regular program lines by plugging the input of a Western Electric 94 type, or similar bridging amplifier, into one of the monitor jacks or by bridging across the output of the amplifier

f. Volume-indicator Meters.—The 22D speech-input equipment provides for the use of either a Western Electric KS-8208 or KS-8218 volume-indicator meter of the improved type, standardized for the measurement of volume levels in program circuits and transmission systems. These meters are available with either of two scales, the KS-8208 meter having the A scale, which is marked from -20 to $+3$ VU above the scale arc, with an arbitrary voltage scale 0 to 100 in small figures below the arc. The KS-8218 volume indicator meter has a B scale in which the 0 to 100 scale markings are in large figures above the arc of the meter scale, with -20 to $+3$ VU markings indicated below the arc. The 100 (0 VU) reference point of the meter is so located on the scale that approximately two-thirds of the available scale length is utilized.

The scale of the meter may be illuminated by operating the LAMP switch on the face of the amplifier-control unit which is connected to two small lamps mounted inside the meter front cover.

The normal indication (deflection to the 0 VU or 100 mark) of the meter can be set to correspond to levels to the outgoing line of $+4$, $+6$, $+8$, $+10$, $+12$, and $+14$ VU by means of the volume-indicator range switch. Normally, a level of $+8$ or $+10$ VU will be required to supply program material to a program line. This range



(a) Rectifier and Filter Unit

(b) Battery Connections

FIG. 11-16.—Power supplies for W.E. 22D speech-input equipment.

switch has an OFF position and a PLATE and a FIL position for checking plate and filament voltages. For the purpose of checking battery voltages, the 0 VU or 100 marking on the scale is used to indicate the minimum operating voltage. Checking may be done at any time, even during program transmission.

g. Power-supply Equipment.—The 22D equipment may be operated either from the alternating-current power-supply line or from a battery supply. For alternating-current operation, a 110–120 volt 50–60 cycle-commercial source capable of supplying approximately 28 watts is required. When operated from batteries, 1.4 amp. at 6 volts and 21 ma. at 180 volts are required.

The alternating-current power unit and the battery-rack assembly are each equipped with a heavy-duty cable terminating in a locking plug. To change from one power supply to another takes only a few seconds.

For alternating-current operation, the power or rectifier-and-filter unit provides all necessary power for filament and plate. One commercial, type 80, vacuum tube serves as the plate-supply rectifier. All power connections to the amplifier-control unit are made with a single 6-ft., heavy-duty five-conductor cable. A plug cap is furnished in the power-unit socket for the purpose of connecting a length of rubber-covered cordage from an alternating-current outlet.

¹ Volume indicators are discussed in detail in the next section.

A schematic circuit diagram of the rectifier and filter unit for alternating-current operation (a) and a diagram of the battery connections (b) for battery operation are shown in Fig. 11-16.

When the equipment is operated from batteries, the required battery rack fits into the lower compartment of the power-supply carrying case. If both alternating-current and battery supply are desired, the alternating-current unit then is placed in the upper compartment. The battery rack holds a full complement of the following recommended or other suitable batteries:

Four Eveready No. 738 or Burgess Z-30-PX batteries are required to provide the necessary 180 volts for plate. Based on semicontinuous operation 6 hr. a day, these batteries should last for 12 hr. or more. An Exide storage battery 3-AC-7 per DB-22334-XA is recommended for filament voltage. This is a 6-volt, non-spillable, lightweight battery. The capacity of this battery is sufficient to operate the amplifier approximately 8½ hr. Dry-cell batteries also can be used in place of the storage battery as a source of filament supply.

Two Burgess 4F2H batteries connected in series (instead of a storage battery) will provide the 6 volts for the filament supply. These batteries mount in the storage-battery compartment of the battery rack.

Where long, dry-cell battery life is of paramount importance, low-filament type tubes may be substituted.

h. Vacuum Tubes and Accessories.—The following items are necessary for the operation of the 22D equipment:

Type of Operation	Tubes Needed
Vacuum tube	2 6J7
	1 6F6
	1 No. 80 for A.C. power unit
Storage battery	2 6J7
	1 6F6
Dry cell	2 6J7 or
	2 6W7G (0.15-amp. heater)
	1 6F6 or
	1 6G6G (0.15-amp. heater)

In addition to the above items, the following accessories may be used with this equipment:

1. *Portable Telephone Set (301A).*—For supervisory communication from the remote pickup point to master control at the studio or transmitter, the remote operator will find the Western Electric 301A portable telephone set extremely useful.

2. *Monitoring Headset.*—One or two Western Electric 1002F headsets are recommended for monitoring purposes. If the highest quality headset monitoring is desired, the Western Electric D97690 headset (equipped with a D90944 cord and 47 type plug) is highly recommended.

3. *Loud-speaker Monitoring.*—When loud-speaker monitoring is desired, a Western Electric 94 type or equivalent amplifier should be employed together with a loud-speaker such as the Western Electric 751B. The 94 type amplifier has a high-impedance bridging-type input which can be bridged either directly across the out-going line or plugged into one of the headset monitoring jacks of the 22 type equipment. A 47 type plug and a cord such as the 630 type referred to under the heading Output Circuit are recommended for this purpose. The 94 type amplifiers are capable of supplying up to 12 watts output (with minor conversions 20 watts) which is adequate for operating one or more speakers of the type mentioned.

4. *Microphone and Accessories.*—Western Electric 618, 630, or 639 type microphones are recommended for use with this equipment. Shielded microphone cordage such as is recommended for use with Western Electric microphones or other low-level high-quality program circuits should be used where necessary.

11.18. Monitor Amplifiers.—Separate amplifiers are desirable for monitoring purposes. As the amplifier input bridges the line, it should have a high impedance in the order of 4,000 to 20,000 ohms so that it will not draw appreciable power from the main load and so that a number of such amplifiers may be added to or removed from the circuit without noticeably affecting the volume level.

The gain and output power depend upon the number of speakers being fed and the method of feeding employed. If the amplifier is to supply all speakers directly, it should be capable of supplying each unit with a power level of about 25 db. If more than one or two speakers are used with this system, a very large output is required. If they are scattered about the building, very high power levels must be impressed upon the cables connecting them to the amplifier. This makes the prevention of cross talk in neighboring circuits a difficult matter. In order to provide for changes to be made in the individual speaker volume, without affecting others connected to the same supply circuits, a constant-impedance attenuation network must be used between each speaker and the line. Such a network is shown in Fig. 11-5.

The larger the number of speakers supplied, the greater the problem of cross talk. Under these conditions it is much better to use a line-bridging monitor amplifier the output of which supplies a moderate power, such as 0 db, to a low-impedance bus which runs to all the speakers. Each speaker is then equipped with an individual amplifier, bridging the bus and capable of raising the volume to any desired level. The manipulation of the volume control which is incorporated in a speaker amplifier will not affect the program level at any other speaker. The use of the line-bridging amplifier feeding the bus serves to isolate the speaker circuits from the line and prevent any short or open circuit in them from affecting it. This system also provides much greater flexibility as speakers may be added to or removed from the circuit, as conditions may require, without noticeable effect on the system.

Line-bridging amplifiers have high-input impedances and are designed to be energized by zero level and give an output of +10 to 20 db. This output is stepped down to line level by a suitable pad between amplifier and line. The advantages of using a pad in this way are discussed under Attenuation Networks (Sec. 11.22).

11.19. Volume Indicators. *a. General Discussion.*—In order to allow the operator to control properly the gain of the system, he must be aware of the exact program level at any instant. For this purpose, a meter,

calibrated in volume units, VU, and connected across the output of the amplifier, is mounted near the main gain control.

Such a meter must read the peak values of the audio-frequency wave and must be capable of very quick response to enable it to follow the rapid variations in program level. If the audio-frequency wave is first rectified and then passed through a suitable direct-current meter, these conditions will be fulfilled.

Until recently, it was customary practice to measure the power level of the program by means of a DB meter, which is really an alternating-current voltmeter calibrated to read 0 db when placed across a 500-ohm load carrying 0.006 watts. This corresponds to a voltage of about 1.73 volts, the normally understood reference level when speaking of power in decibels being 0.006 watts. However, this reference level was not completely standard throughout the industry, some stations using 0.0125 watts as their reference level. In fact any arbitrary power level and impedance value may be used for a DB meter.

Even more confusing than arbitrarily chosen reference levels was the lack of standardization in the speed of meter movements. An example of how this affects operations is given in the following paragraph.

Suppose that there are two studios A and B. The first is equipped with a slow meter, M_1 , the second with a meter M_2 , which responds quickly. We will say that the receiving point (such as the transmitter) is checking the level from both studios by means of a slow meter M_1 .

Both studio meters have been adjusted so that they read 0 db for a steady note such as is obtained from an audio-frequency oscillator. A speaker is using studio A, and the gain is adjusted until the peaks caused by his voice register 0 db. As he emphasizes occasional words, his peaks are high compared with his average level.

Suppose now this same speaker is transferred to studio B and the same adjustment made. The checking point will indicate a lower level; how much lower depends upon the amplitude of the speaker's highest peaks and the length of time they last. As the peaks are now practically instantaneous, the studio meter M_2 , having less inertia, gives a truer indication of the height of the transient voltage than does the checking meter M_1 , the input to which must be sustained for an appreciable time before the needle rises to a maximum. In order to get the same response as before on the checking meter M_1 , it may be necessary to raise the gain until the live meter M_2 reads +6 db on peaks. The program will then have the same level as in the first place.

Suppose that the next program is a band in studio B. The peak values of such combinations of instruments as a band are usually sustained over appreciably long intervals of time. The level is set as before on meter M_1 , so that the program peaks at +6 db. As the peak sound level is long enough to overcome the inertia of both meters entirely, the effect of the difference in inertia between them is nullified. The checking meter M_1 will then indicate a program level of +6 db. If the position of the meters were reversed in the first case, the conditions would also be reversed. It can be seen that, if the two meters M_1 and M_2 have not exactly the same degree of damping, they will not read alike unless the input is a steady tone. For this reason the type of indicator and its degree of damping should be standardized for a studio system or chain network.

The broadcast and telephone industries have adopted a standard meter for use as a volume indicator. This meter is calibrated in VU's (volume units), and the definition of the unit embraces a definition of the meter, taking into account all its important characteristics such as speed of rise, speed of return, insertion resistance, and methods of marking the scale. Thus each VU meter is exactly like every other VU meter, and whatever reading is given under program conditions by one meter corresponding readings will be given by any other VU meter.

The VU meter unit consists of a copper oxide type alternating-current voltmeter manufactured to exact specifications as mentioned above. Considered as part of the meter is a resistance network which enables the unit to be set for different sensitivities. The actual VU level being read is always the algebraic addition of the meter reading and resistance switch-setting reading. For instance, if the meter reads 0 VU and the switch is set at +4 VU, the level value being measured is +4 VU. Or if the meter reads -2 VU and the switch is set at +8 VU, the value of the level being read is +6 VU.

The meter gives accurate VU readings only across a 600-ohm load, and 0 VU is indicated when 0.001 watt is delivered to the 600-ohm load.

The meter has a rapid rise and slow fall which makes it easy to follow program peaks and modulation envelope values. Besides showing VU's, the VU meter is also marked to indicate percentage of modulation. Zero VU or 100 per cent modulation is indicated on the meter before the top of the scale is reached to allow for occasional overshooting of program peaks. The frequency response of the meter is good enough to be neglected from 20 to 15,000 cycles when the meter is used to make frequency-response runs on broadcast equipment, and no correction factor is ordinarily applied.

A variation in level of any number of VU's gives the same change in DB, and if 0 DB is considered as 0.001 watt across 600 ohms, the values of DB and VU for constant levels would be identical.

A VU meter can always be used as a DB meter, but a DB meter can only be used as a VU meter provided that steady readings are being obtained. When varying levels are encountered, the speed of meter movements must be taken into account and the DB meter and VU meter would probably read different values under such conditions.

Gain or loss in the equipment in terms of power level may be measured in DB's or VU's under steady-state conditions. Thus, to say that a pad has a loss of 10 db is exactly the same statement as saying that the pad has a loss of 10 VU.

b. Precautions in the Use of Volume Indicators.—If a volume indicator is placed directly across the line, there may be a discrepancy of many VU's between the readings given for the same actual power level as the frequency in the line varies from high to low. This is because the imped-

ance of the line varies with frequency because of the distributed capacity in the line. The meter should always be isolated from the line by a suitable pad. When used in this manner, the resistance across it is kept practically constant at all frequencies, and the meter calibration remains accurate.

A typical set-up is to have the output transformer work into a pad which feeds the line. The meter is then placed across either termination of the pad. If it is placed across the pad input, a better isolation will be obtained; but the reading will be higher than the actual line level by the value of the pad. The results obtained by placing it at the line end of the pad are usually sufficiently accurate for the purpose. When used to make frequency runs, the meter should always be isolated from the equipment under test by a pad of the proper value.

c. Note on VU Problems.—Problems involving volume units are solved exactly as any DB problems inasmuch as a change of any number of VU's corresponds to a change of a similar number of DB's. If 0 db is taken as 0.001 watt, the terms VU and DB may be substituted in any DB problem.

11.20. Equalizers and Equalizing. *a. Requirements.*—All untreated long lines carrying programs will deliver at their remote end a reproduction lacking in high frequencies. The longer the line, the greater its distributed capacity; and it is this capacity between the conductors which tends to act as a short circuit to the higher program frequencies. Because the reactance of the line decreases as the frequency increases, the higher the note to be transmitted, the greater the attenuation introduced by the line.

To correct this defect, adjustable filters called *equalizers* are inserted in the line. These are set to attenuate (filter) the low notes in exactly the same proportion as the line loses the highs. In this way the loss occasioned at every frequency is equal, and the program reaching the far end of the line is an exact, though attenuated, reproduction of that impressed.

Common forms of equalizers and their characteristic curves are shown in Fig. 11-7. The coil L possesses a low ohmic resistance (about 3 ohms) and is resonant with the condenser at 5,000 cycles. Some equalizers designed for very long lines, meant for speech only, resonate at 3,000 cycles. In series with the resonant circuit is a decade resistance box R . The whole unit is placed across the line as shown.

The parallel-resonant circuit (*a*) offers an extremely high impedance to frequencies around 5,000 cycles, and very little energy at the higher frequencies is lost through this circuit. As the frequency drops below the resonant value, the impedance of the tuned circuit becomes low and allows the lower frequencies to be shunted through it and around the line termination to an extent governed by the setting of the decade box

R. By adjustment of this resistance the equalizer can be made to control within its limits the frequency response of any line. If the line loss is greater than about 12 db at 1,000 cycles, additional equalization will probably be necessary. Equalizers may then be used in parallel, or special types having a greater low-frequency loss may be employed. It must be remembered that the greater the equalization, the greater the overall attenuation.

b. Operation.—When a parallel-resonant circuit is connected across a line as in Fig. 11-17(a), it represents a high-impedance load across it. Consequently a maximum voltage will be developed across it at the particular frequency to which it is

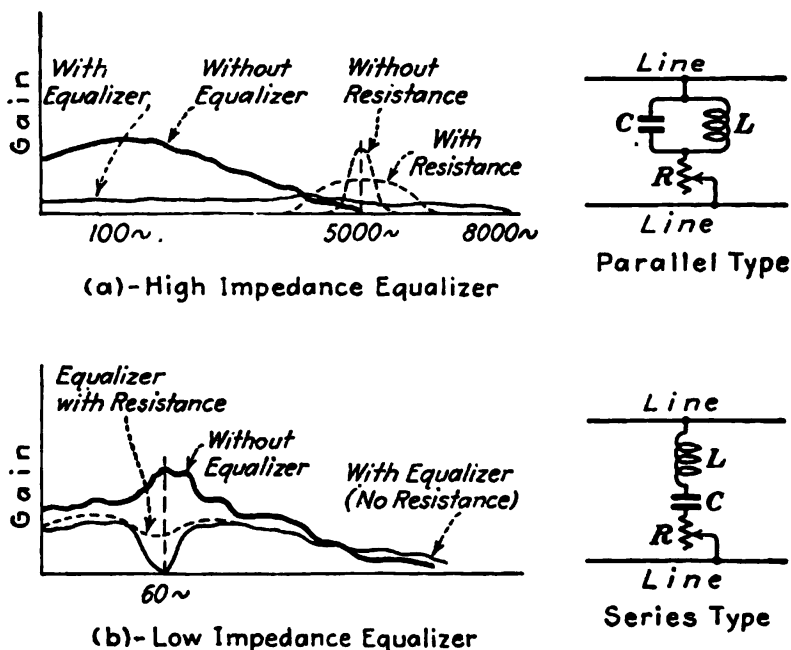


FIG. 11-17.—Parallel- and series-resonance equalizers.

resonant. Let us assume for example that an audio-frequency line with considerable length attenuates most of the higher range of frequencies above 5,000 cycles owing to the distributed capacity in the line. If the equalizer is adjusted to say 5,000 cycles, the feeble energy developed across it at the 5,000-cycle frequency will be raised by the e.m.f. developed across the high impedance. Thus, the frequency characteristic will be raised at the higher frequencies and decreased at the lower frequencies. Hence, the overall frequency will be flattened out to effect a straighter characteristic over a wider band. This condition is illustrated in the curves in diagram (a). It will be seen from the dotted curves that the series resistance serves to flatten out the characteristic at the resonant frequency.

The series-resonant equalizer of diagram (b) will serve to function in a way just opposite to that of the parallel circuit since, when it is adjusted to resonance, it functions as a low-impedance or attenuating device. That is to say, when the reactances X_L and X_C are equal, the effective reactance will be zero, since the reactances cancel each other and consequently no e.m.f. will be developed across it. Hence only the series resistance will be effective. From this it may be seen that if it is desired to attenuate a certain frequency a series-resonant equalizer must be used.

The curves in diagram (b) illustrate the effect of attenuation upon a certain frequency by adjusting L and C to equal reactance values. The amount of attenuation effected by L and C is governed by the resistance R , the amount of attenuation varying with the value of R in the circuit to the right.

c. Use.—An equalizer may be used at any point in the line, but it is best practice to insert it at the receiving end. It is at this point that the quality of reception will be judged, and emergency conditions which may require readjustment of the equalization must in most cases be met. There are other important considerations. With the filter (equalizer) at the terminating end, any low-frequency noises picked up by the line will be attenuated by the equalizer. The longer the line, the more noise there is apt to be picked up; but, as the equalizer resistance will be correspondingly low, the greater will be its effectiveness in decreasing the noise level. If the low frequencies are attenuated at the sending end, the line noises will arrive at the receiving end proportionately greater in respect to the program than they would be with the filter at the terminating end.

If a filter circuit used with zero or low resistance is located at the point of origin, it offers a very low impedance at the lower frequencies which impedance is directly across the output equipment. Additional precautions are then necessary to isolate sufficiently the volume indicator and amplifier output to insure that the frequency response of both units remains unaffected.

11.21. Frequency Runs.—In order to equalize a line, an audio-frequency voltage of constant value, but varying in frequency from that of the lowest tone to that of the highest to be transmitted, is impressed upon the circuit. The filter is then adjusted until the volume indicator at the remote end gives the same reading, within the prescribed tolerances, at each frequency.

The source of steady tone is an audio-frequency oscillator. In order to get accurate results it is important that the harmonic content of the impressed frequency be negligible in value. The oscillator output is amplified and impressed on the line through an isolating pad. It is very important that the impedance across the input of the volume indicator be the same regardless of frequency. For this reason the instrument should be bridged across the amplifier side of the pad. Runs made without such precautions as to the volume-indicator termination may be a number of decibels off at either the low or high end, depending upon the termination.

At the receiving end, the line output, after being equalized, is passed into a suitable line-terminating coil, the output of which is passed through a pad. The power level at the pad output may be measured directly on a sensitive thermocouple meter calibrated directly in decibels. More often it is subject to further amplification by the equipment to be used in conjunction with that line, or failing this, by an amplifier having known characteristics, the output of which is fed to a properly terminated volume indicator.

Preliminary adjustments of the equalizer resistance at three or four of the most important frequencies, perhaps at 100, 1,000, 3,000, and

5,000 cycles, are made to determine the approximate value of the resistance required. Finer adjustments are then made until the response of the line is sufficiently flat over the required frequency range.

Until recently lines for remote pickups have not been equalized for frequencies over 5,000 cycles. There are now available, and in use at the better stations, filters which can flatten moderately long lines up to 8,000 cycles. Of course, if necessary, lines can be equalized over a range of frequencies wide enough to transmit a broader frequency spectrum. The lines between studio and transmitter are usually made good from 30 up to 8,000 or 10,000 cycles, and in some instances up to 15,000 cycles.

When broadcasting from remote points there are usually at least two separate telephone lines installed. One is a *radio line* to carry the program, and the other is a *talking line* used for communication between the studio and the remote point. To equalize such lines, a regular remote-control amplifier is sent to the remote terminating point. Then the output of an audio oscillator is impressed upon the talking line at the studio end. These oscillations are amplified by the remote amplifier and impressed upon the radio line at the remote end. Then, by adjusting the gain of the remote amplifier, a given level is secured. At the studio end, the radio line is then equalized, readings being taken on the equipment which will be normally associated with it. After this process is completed, the lines are reversed and the talking line is equalized in the same fashion. Thus, should a breakdown occur on the radio line, the talking line may be substituted without the quality of the reproduction suffering.

If the lines are long, it is necessary to insert *booster amplifiers* at intervals. This keeps the program level well above the line noise at all points. For high-quality transmission such boosters should be inserted every 10 to 20 or more miles, depending a great deal upon the natural noise level in the cable and the amount of equalization loss entailed. The higher the frequencies equalized for, the greater the loss in program level and the closer the amplifiers. Such units are supplied by the telephone company as part of its service.

It should be mentioned that radio and talking lines do not go through a switchboard operator but are permanently connected between the studio and the remote pickup point. The radio lines should be tested daily with an oscillator to determine their frequency and gain characteristics. Occasionally the intermediate boosters introduce distortion due to defective tubes. This must be reported to the telephone company.

11.22. Attenuation Networks.—These networks are used when it is desired to attenuate a transmission, isolate equipment, change transmission impedance, or balance a line.

There are various forms of attenuation networks, the most common being the *L*, *T*, and *H* pads. The names are derived from the arrangement of the resistors comprising them as illustrated in Fig. 11-18(a), (b), and (c), respectively.

The *L* or *T* pad is used when line balance is not a factor. The *H* type, which is the one most commonly used in broadcasting, not only does not disturb the balance of the conductor impedances, but actually

serves to equalize them by decreasing the ratio of unbalance if it is present. The greater the value of the series elements, the more pronounced this effect.

In order to prevent reflections from taking place, the input and output impedances of the pad must match that of their terminations. A simple analogy of electrical reflection is presented by light which when striking a surface is partly reflected and partly absorbed. A mirror absorbs very little light and reflects a good deal, a truly dark object absorbs all the light and reflects none. In an electric circuit, that portion of the

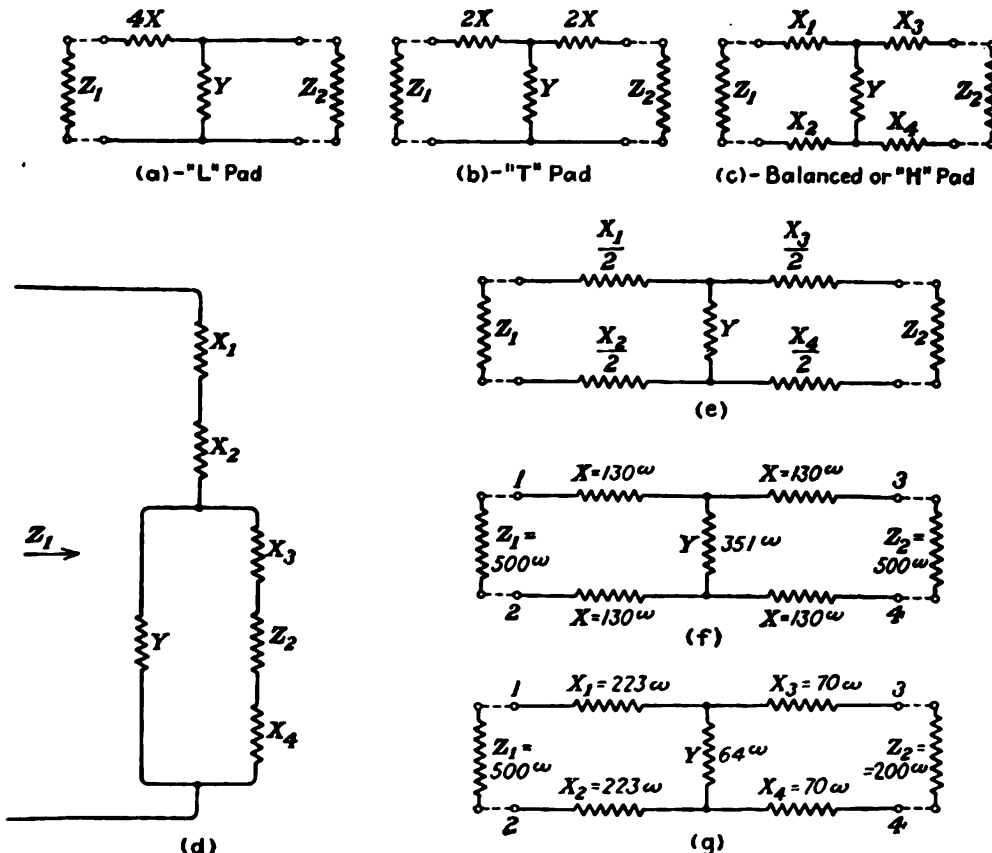


FIG. 11-18.—Various types of attenuation networks.

energy not absorbed by the termination impedance will be reflected back to the source, just as is the light striking a partially reflecting surface. At the source, reflection will again take place, and the energy will travel back and forth between the source and the termination until it gradually expends itself. If the impedance of the termination matches that of the source, all the energy will be absorbed by it and none reflected. This is one of the reasons why impedance matching is so important, particularly on long lines or involved systems.

By means of the following equations the proper values of the various resistance units of a pad may be calculated.

FORMULAS APPLYING TO PADS WORKING BETWEEN EQUAL IMPEDANCES

Note: The letters X , Y , and Z as used in the following equations refer to the resistance branches so lettered in the pad circuits in Fig. 11-18.

For the H Pad [see diagram (c)]:

$$X = \frac{Z(K - 1)}{2(K + 1)}$$

but if

$$\frac{K - 1}{K + 1} = X^\kappa$$

then

$$X = \frac{Z}{2} X^\kappa \quad (1)$$

$$Y = \frac{2ZK}{(K + 1)(K - 1)} = 2Z \frac{K}{K^2 - 1}$$

but if

$$\frac{K}{K^2 - 1} = Y^\kappa$$

then

$$Y = 2ZY^\kappa \quad (2)$$

Proof:

$$Z = 2 \sqrt{X(X + Y)}$$

The constant K is fixed by the attenuation desired and is found in this type of problem by working out the expression, $\text{db} = 20 \log K$.

Table XIB on page 587 gives the values of X^κ and Y^κ for various values of decibels (db).

$$K = \text{antilog} \frac{\text{db}}{20} \quad (3)$$

As an example a pad having an impedance of 500 to 500 ohms and a loss of 10 db will be solved.

From the above expression

$$K = \text{antilog} \frac{10}{20} = K = \text{antilog} 0.5$$

but

$$\text{antilog} 0.5 = 3.16$$

therefore,

$$K = 3.16$$

Then

$$X = \frac{Z(K - 1)}{2(K + 1)} = \frac{500 \times 2.16}{2 \times 4.16} = \frac{1,080}{8.32} = 130$$

TABLE XIB.—THE CONSTANTS* X^K and Y^K FOR H AND T PAD COMPUTATIONS
For pads working between equal impedances only

db	K	X^K	Y^K
1	1.122	0.057	4.48
2	1.259	0.115	2.135
3	1.413	0.171	1.438
4	1.585	0.226	1.036
5	1.778	0.280	0.823
6	1.995	0.333	0.669
7	2.24	0.382	0.560
8	2.51	0.430	0.473
9	2.82	0.481	0.405
10	3.16	0.519	0.351
11	3.55	0.560	0.305
12	3.98	0.597	0.268
13	4.47	0.636	0.235
14	5.01	0.667	0.207
15	5.62	0.697	0.184
16	6.31	0.723	0.162
17	7.08	0.752	0.144
18	7.94	0.776	0.127
19	8.91	0.798	0.116
20	10.0	0.818	0.101
21	11.2	0.836	0.090
22	12.6	0.853	0.079
23	14.1	0.867	0.071
24	15.8	0.880	0.063
25	17.8	0.893	0.056
26	20.0	0.904	0.050
27	22.4	0.914	0.044
28	25.1	0.923	0.039
29	28.2	0.931	0.035
30	31.6	0.938	0.031
31	35.5	0.945	0.028
32	39.8	0.950	0.025
33	44.7	0.956	0.022
34	50.1	0.960	0.019
35	56.2	0.965	0.017
36	63.1	0.967	0.015
37	70.8	0.972	0.014
38	79.4	0.975	0.012
39	89.1	0.977	0.011
40	100	0.980	0.010
41	112	0.982	0.0089
42	126	0.984	0.0079
43	141	0.985	0.0070
44	158	0.987	0.0063
45	178	0.988	0.0056
46	200	0.990	0.0050
47	224	0.991	0.0044
48	251	0.992	0.0039
49	282	0.993	0.0035
50	316	0.993	0.0031

$$* X^K = \frac{K-1}{K+1}; Y^K = \frac{K}{K^2-1}; K = \text{antilog } \frac{db}{20}; K = \frac{\text{input } E \text{ or } I}{\text{output } E \text{ or } I}$$

or, taking the value of X^* from the table, which is approximately 0.52, the expression becomes

$$X = \frac{Z}{2} (X^*) = 250 \times 0.52 = 130^*$$

It is, therefore, quicker to take the value from the table than to work out the fractional expression involving K . Proceeding, we find

$$Y = \frac{2ZK}{(K+1)(K-1)} = 2Z \frac{K}{K^2-1} = 2Z \frac{3.16}{8.98} = 2Z \ 0.351$$

Therefore,

$$Y = 2Z \times 0.351 = 351^*$$

or, taking the value of Y^* from the table, which is 0.351, the expression becomes

$$Y = 2Z \times 0.351 = 351^*$$

This pad is shown in diagram (f).

Again it is seen that the table of values reduces the mathematical labor involved. It is seen then that by the aid of the table it is a relatively simple job to compute any value of H or T pad.

It now remains to prove that this result gives the required pad. First, a check of the impedance match will be made. Looking into it from the input, the impedance of the pad should be 500 ohms when terminated by its proper resistance.

By rearranging the circuit diagram a little, the checking process may be facilitated. Thus the H pad, shown in diagram (f), becomes as shown in diagram (d). From the viewpoint of the generator there are two resistors X_1 and X_2 , having a total value of 260 ohms, in series with a parallel combination consisting of Y which is shunted by X_3, Z, X_4 , the load resistance being Z_1 . The lettering on drawings (c) and (d) denote equivalent resistors, that is, X_1 in drawing (c) equals X_1 in drawing (d), and so on. The parallel combination has a total resistance of about 240 ohms, as can easily be verified. Thus the total resistance the combination presents to the source is 500 ohms. This value is quite accurate enough for the work involved and is probably as accurate as would be obtainable in the actual construction of a pad owing to the tolerances of the commercial resistors used for this purpose.

As the impedances are equal, and the pad symmetrical, there is no necessity to check the output impedance as it must be the same as the input impedance just checked.

An easy way to check the loss is to imagine a convenient value of power as being impressed upon the input terminals and compute from this how much actually reaches the termination.

Thus, in the example just cited, assume that a power of 500 watts is being impressed at the input. This will produce a current of 1 amp., as the pad presents a 500-ohm resistance and $W = I^2R$. One ampere then flows through the parallel combination shown in diagram (d). This current will divide itself between the two paths in proportion to their conductances; that is, inversely proportional to their resistances. Thus, if for example we let $Y = 351$ and $X_3Z_2X_4 = 760$ ohms, then

$$I_{X_3Z_2X_4}:I_Y = 351:760 \text{ and } I_{X_3Z_2X_4} = \text{total } I \left(\frac{351}{351 + 760} \right) = 0.310 \text{ amp.}$$

As the value of current in all parts of a series circuit is constant, 0.310 amp. will flow through Z_2 . The power delivered will then be

$$I^2R = 0.1 \times 500 = 50 \text{ watts}$$

and the loss in decibels may be computed as follows:

$$\text{db} = 10 \log \frac{P_1}{P_2} = 10 \log \frac{500}{50} = 10 \log 10$$

but $\log 10 = 1$, therefore $\text{db} = 10$. Thus the pad has the required termination.

For the T Pad [see diagram (b)]: $X = Z(X^\kappa)$ and $Y = 2Z(Y^\kappa)$ (X^κ and Y^κ taken from table).

FORMULAS APPLYING WHEN THE INPUT AND OUTPUT IMPEDANCES ARE NOT EQUAL

Then,

$$\text{db} = 20 \log \frac{I_1 \sqrt{R_1}}{I_2 \sqrt{R_2}} \quad (4)$$

Formulas for a T pad to work between unequal impedances follow¹ [the symbols are as illustrated in diagram (e)]:

$$Y = 2 \frac{Z_1}{s} \left(\frac{K}{K^2 - 1} \right) \quad (5)$$

$$X_1 = Z_1 \frac{\left(K^2 + 1 - \frac{2K}{s} \right)}{K^2 - 1} \quad (6)$$

$$X_3 = Z_2 \left(\frac{K^2 + 1 - 2Ks}{K^2 - 1} \right) \quad (7)$$

where

$$s = \sqrt{\frac{Z_1}{Z_2}}$$

¹ Formulas 5, 6, and 7 are based on those given by P. K. McElroy, *Designing Resistive Attenuation Networks*, *Proc. I.R.E.*, Vol. 23, No. 3, March, 1935.

The constant K has a value depending upon the attenuation and is found by working out the expression $\text{db} = 20 \log K$,

$$K = \text{antilog } \frac{\text{db}}{20}$$

Let us calculate an H pad to work between 500 and 200 ohms and having a loss of 20 db. The finished pad is shown in diagram (g). Note that the X values must be divided by 2 as per diagram (e).

Solving:

$$K = \text{antilog } \frac{\text{db}}{20}; \quad K = \text{antilog } \frac{20}{20}; \quad K = \text{antilog } 1; \quad K = 10$$

$$s = \sqrt{\frac{500}{200}} = 1.58$$

$$Y = 2 \times 316 \times 0.10 = 63$$

$$X_{1,2} = 500 \times 0.90 = 450 \div 2 = 225$$

$$X_{3,4} = 200 \times 0.70 = 140 \div 2 = 70$$

This may be checked for impedance in the same manner as the previous pad. It should be checked from both terminations, however, as it works between uneven impedances.

The check for proper attenuation is accomplished in the same manner as the previous pad.

It will be noted that it is impossible to construct such a pad to have *any* loss or to work between *any* values of impedances, as to accomplish this negative values of resistance would be necessary.

The isolation effect of a pad upon the equipment it is used with is most important. Let us take for example an amplifier having a 500-ohm output and used between remote points and the studios. The output transformer of the amplifier is designed to work into a load of 500 ohms. If the load is very much decreased, the primary inductance of the transformer will be materially lessened with a resultant loss of the lower frequencies. If the output amplifier transformer is terminated directly by the line it is working into, a different impedance for each frequency will result, owing to the difference in line lengths and distributed capacities. Hence the frequency response of the amplifier will change with the termination. If, instead, it is terminated in a pad having a sufficiently high loss, this will isolate it from the line enough to guarantee the same characteristics regardless of its location or the pad termination.

Let us find the isolation afforded by a 500-to-500 ohm H pad of 10-db loss and compare it with that offered by a similar network having a 40-db loss. The values for a 10-db pad are $X = 130$ and $Y = 351$. Referring to diagram (c) and substituting these values we find that, under the extreme circumstances of zero termination of the pad output, the resist-

ance across the transformer would be 610 ohms instead of 500, a variation of about 22 per cent. In the other extreme possibility of a short circuit across the pad output, the resistance across the transformer would be 410 ohms instead of 500, a variation of 18 per cent. Thus, using a 10-db pad, the greatest possible variation at the transformer does not much exceed 100 ohms, while if the transformer were used without the pad it would range from zero to an infinite value.

The values for the 40-db pad would be $X = 245$ and $Y = 10$. This pad then represents a resistance of 499.9 ohms when properly terminated. On open circuit at its output this changes to 500 ohms, or a maximum change of about 0.02 per cent. Such a pad, therefore, offers practically perfect isolation against impedance changes affecting the equipment with which it is used.

CHAPTER 12

BROADCAST AM TRANSMITTERS¹

The term *standard broadcast station* as defined by the FCC means a station licensed for the transmission of radiotelephone emissions primarily intended to be received by the general public and operated on a channel in the band 550 to 1600 kilocycles.

I. BROADCAST TRANSMITTERS

12.1. The broadcast station consists essentially of a studio, a radio transmitter, and a radiating system. A modern arrangement of a



FIG. 12-1.—Master control desk of 50,000-watt broadcast station. (Courtesy of Western Electric Co.)

50,000-watt station, showing the main control console and the transmitter units, is shown in Fig. 12-1. A block diagram of the entire system is shown in Fig. 12-2. Here it is seen that the studio is located at a distance from the radio transmitter. This is the general practice at all except the smaller stations and is found to have many advantages. As the studio is the point at which the programs originate and is the central point of

¹ Broadcast amplitude-modulation transmitters.

control and distribution of lines connecting with various sources of program throughout a city, it is desirable to have the studio located conveniently in the city.

The radio transmitter, however, is best located outside of the built-up areas, where the radiating system is not affected by large buildings and other steel structures. A better field-intensity pattern and overall coverage are then obtained.

The studio and the radio transmitter are interconnected by means of program-transmission lines, which are special telephone lines designed to have a uniform-frequency transmission characteristic from approximately 60 to 6,000 cycles. Two or more independent lines are usually provided to insure uninterrupted service. There are also private intercommunicating telephone lines to permit the operating personnel of the studio and radio transmitter to be in immediate contact whenever necessary. The program lines are terminated in suitable switching and attenuating

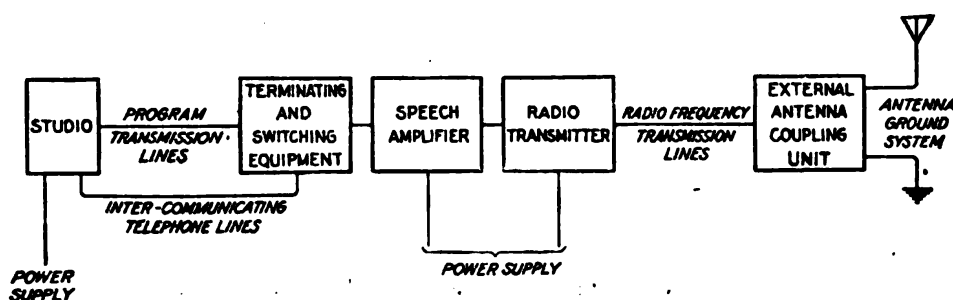


FIG. 12-2.—Block diagram showing arrangement of broadcast-studio and transmitter equipment.

apparatus which permits the selection of a program line and also controls the input level to the speech amplifier. This amplifier brings the low program level coming in on the lines up to the value necessary to feed into the radio transmitter where the carrier is modulated. The output of the radio transmitter is then fed into a radio-frequency transmission line which transmits the modulated carrier power to the antenna-coupling unit. This unit is essentially a transformer or condenser coupling the transmission line to the antenna-ground system with a proper matching of impedances and at the same time maintaining a proper balance of the transmission line. The antenna and ground constitute the radiating system of the broadcast station and may be in any one of the several conventional forms now in use.

The box layout shown in Fig. 12-2 may, of course, be varied to meet different conditions. For example, the studio and radio transmitter may be located together, thereby eliminating the expense of high-quality program-transmission lines. On the other hand, the radio transmitter may also be operated directly into the antenna-ground system, thus eliminating the radio-frequency transmission line and coupling unit with their attendant losses. In general, broadcast stations of less than 5-kw.

output do not employ a transmission line or external coupling unit as the radiator is usually located near the transmitter.

The studio with all its associated equipment was discussed in the preceding chapter. The switching apparatus and speech amplifier at the radio transmitter are similar to studio equipment, the only difference being in their application. A detailed discussion of the operation of the radio transmitter and all its associated apparatus follows.

12.2. Definition and Rating of the Transmitter.—By *transmitter* is meant that apparatus wherein a fundamental radio-frequency wave is generated, amplified, modulated (further amplified in some cases), and finally delivered into a radiating system. By *radio-transmitting equipment* is meant the radio transmitter and all apparatus directly associated with it, including the speech-input amplifier, monitors, radio-frequency transmission line, antenna-coupling unit, and all power-supply and control circuits.

Radio-transmitting equipments may be classified in different ways such as low- or high-power; motor-generator-operated; direct-current-rectifier- and motor-generator-operated; or all-alternating-current-operated; low- or high-level modulation; direct- or transmission-line-fed antenna-ground system.

The power rating of a radio transmitter is purely a relative figure, and the dividing line may be chosen arbitrarily. At present, carrier powers of less than 5 kw. may be called *low* power, and 5 kw. or more, *high* power. The maximum rated carrier power of a broadcast transmitter is determined by the number and types of tubes in the last radio stage and by the type of modulation employed.

For high-level modulation, the maximum rated carrier power of a transmitter is the same as the total installed tube-power capacity of the last stage. For example, if two RCA-833 tubes are employed, this power is 1,000 watts, because these tubes are given a fixed power rating of 500 watts each by the manufacturer when operated under the above conditions with proper plate, filament, and bias voltages and output impedances.

When low-level modulation is employed, the maximum rated carrier is one-fourth to two-thirds the total installed tube-power capacity of the last radio stage. In this case, if two RCA-833 tubes are used in the last radio stage, the rated power would be 250 watts.

If grid-bias modulation is employed in the last radio stage, the maximum rated carrier power is the same as the total installed tube-power capacity of that stage, as determined by the FCC tube-power rating for this type of modulation.

It must be remembered that the three above conditions deal with maximum rated carrier power of the transmitter, not with actual authorized operating power of the broadcast station. In general, the two powers are the same, but sometimes the latter is less than the former, that is to

say, a station may be authorized to operate on 750 or 500 watts although it is really capable of 1,000 watts output. However, a broadcast station with an authorized carrier-wave power over 5,000 watts does not generally install a transmitter with maximum rated power exceeding twice the operating power.

12.3. The operating power of a broadcast station (which is the same as the licensed or authorized power within specified tolerances) must be determined by the *direct-measurement method* except under the following conditions when the *indirect-measurement method* may be used:

a. In case of an emergency where the licensed antenna has been damaged or destroyed by storm or other cause beyond the control of the licensee or pending completion of authorized changes in the antenna system.

b. Upon making any change in the antenna system, or in antenna-current measuring instruments, or any other change which may alter the characteristics of the antenna. However, the licensee shall immediately make a new determination of the antenna resistance and shall submit application for authority to determine power by the direct-measurement method on the basis of the new measurements.

The antenna-input power as determined by the direct-measurement method is (I^2R) , the square of the antenna current times the antenna resistance at the point where the current is measured at the operating frequency. The antenna-resistance measurements must be made according to authorized methods (see Sec. 12.14), and the antenna current must be measured by an ammeter of accepted accuracy.

The operating power as determined by the indirect-measurement method from the plate-input power of the last radio stage is equal to the product of the plate voltage, the total plate current in this stage, and a factor F , which is determined by the type of modulation used and the maximum rated carrier power of the transmitter as shown in Table XIIA on page 596.

As shown in Table XIIA, the factor F for high-level modulation for 100 to 1,000 watts output is 0.70; for 5,000 watts or over, 0.80. Thus a transmitter using high-level modulation at a rated carrier power of 1,000 watts would have its operating power, as determined by the indirect method, computed as follows: Assuming the plate potential is 3,000 volts and the plate current to the final radio-frequency stage 0.555 amp., then:

$$\text{Operating power} = E \times I \times F = 3,000 \times 0.555 \times 0.70 = 1,166 \text{ watts}$$

Obviously, this power is too high and would have to be reduced by reducing the plate potential to about 2,800 volts so that the output would not exceed 1,000 watts.

This is merely another way of saying that the plate power efficiency is 70 per cent, but it is a reasonably accurate check on the operating power of the transmitter when the direct-measurement method cannot be used, provided that operating constants, such as plate voltage, plate current,

TABLE XIIA.—FACTOR F FOR CALCULATING OPERATING POWERA. FACTOR TO BE USED FOR STATIONS EMPLOYING PLATE MODULATION IN THE LAST RADIO STAGE¹

	Factor F to be used in determining the operating power from the plate input power
Maximum rated carrier power of transmitter ²	
100–1,000 watts.....	0.70
5,000 and over watts.....	0.80

B. FACTOR TO BE USED FOR STATIONS OF ALL POWERS USING LOW-LEVEL MODULATION

	Factor F to be used in determining the operating power from the plate input power
Class of power amplifier in the last radio stage	
Class B.....	0.35
Class BC ³	0.65

C. FACTORS TO BE USED FOR STATIONS OF ALL POWERS EMPLOYING GRID MODULATION IN THE LAST RADIO STAGE

	Factor F to be used in determining the operating power from the plate input power
Type of tube in the last radio stage	
Table C tubes.....	0.25
Table D tubes.....	0.35

¹ See "Power Rating of Vacuum Tubes" in the FCC publication "Standards of Good Engineering Practice Concerning Standard Broadcast Stations."

² The maximum rated carrier power must be distinguished from the operating power. See sections 2.18 and 2.19 in FCC "General Rules and Regulations."

³ All linear amplifier operation where efficiency approaches that of class C operation.

radio-frequency input voltage, and output impedance, are all properly adjusted in the last radio-frequency stage.

With low-level modulation, the factor F is 0.35 for transmitters using a class B power amplifier. For transmitters that use a class BC power amplifier, the factor F is 0.65. For example, if an operating power of 1,000 watts and a plate potential of 3,000 volts are used with a class BC power amplifier, the plate-input power is $1,000/0.65 = 1,538$ watts. Therefore, the total plate current must be $W/E = 1,538/3,000 = 0.512$ amp.

Where grid-bias modulation is employed in the last radio-frequency stage, the factor F is 0.25 for transmitters using, for example, a Western Electric 270A tube. Assume, once again, a plate potential of 3,000 volts; let the plate current be 0.333 amp. The operating power will then be $3,000 \times 0.333 \times 0.25 = 250$ watts.

These various figures of the percentage efficiency of the plate-input powers are an indication of the optimum operating conditions for the particular type of tube and method of modulation employed in the radio

transmitter. That is, for a certain type of modulation it has been found that the best operating conditions will result in obtaining a certain plate-power efficiency and that any great deviation from that efficiency is caused by incorrect operating voltages or impedances with the result that the modulated carrier is distorted to some greater or smaller degree.

Although modulation has been referred to several times, and the factor F is largely determined by the type of modulation used, it must be remembered that all measurements and calculations of operating power, by either the direct or indirect method, must be made only with the carrier unmodulated.

If the operating power of the broadcast station is less than the maximum rated carrier power and the indirect-measurement method is used for determining the operating power, the above stated values of the factor F still must be adhered to, even though the output impedance and input radio-frequency voltage have to be readjusted in order to maintain the plate current at such a value that the

$$\text{Output power} = \text{plate volts} \times \text{plate amperes} \times F$$

Thus,

$$P_o = E_p \times I_p \times F \quad (1)$$

A broadcast station may not at any time have an operating power more than 5 per cent above or less than 10 per cent below the rated carrier power. A station may not be operated with a greater percentage of modulation than that for which the transmitter was designed. A station is not permitted to operate at any other than the assigned power output without specific authorization from the Federal licensing authority.

The radio transmitter is really the heart of the broadcast station, for it is here that the medium for conveying a program, speech, music, or other intelligence from the sender to the receiver, that is, the fundamental radio-frequency wave, is generated, amplified, and modulated with a certain program and delivered to the radiating system. Although a transmitter may be designed electrically and mechanically in hundreds of different styles and layouts, still the basic principles of generation, amplification, and modulation must be strictly adhered to (see Chap. 4). Figure 4-1(c) is a block diagram giving a possible arrangement of a transmitter employing low-level modulation.

12.4. Frequency Control.—Owing to the congestion of assigned frequencies in the broadcast band, it has been found necessary to demand the maintenance of each station on its particular frequency in order to reduce interference among stations in radio receivers. Early transmitters employed a simple vacuum-tube oscillator [see Fig. 4-1(a)], consisting of a tuned output circuit with sufficient feedback of energy from the output to the input circuits to cause sustained or continuous oscillations

in the former. But it was found that many factors affected the stability of the oscillator, such as plate and filament voltages, temperatures, circuit constants which varied with aging, tube constants, and so on.

The advent of the crystal-controlled oscillator resulted in the solution of the problem of stabilization to a certain degree. The frequency is still affected by the above-mentioned factors but only very slightly compared with the stabilizing effect of the quartz crystal. However, the resonant frequency of the crystal may be changed by the ambient temperature and by the value of shunting capacity across it. Once the circuit is assembled, the capacity may be considered constant. The temperature range must be kept within very narrow limits by special housing and by automatic-control circuits.

In practice, the oscillator must be designed so that the operating frequency of the broadcast station will be maintained within 20 cycles of the assigned frequency. Furthermore a means must be provided for checking this frequency. This is usually accomplished by having another crystal-controlled oscillator capable of at least the same precision as the oscillator in the transmitter but operating entirely independently of the transmitter. The frequency of the transmitter is then compared with that of this separate oscillator or *frequency monitor* as it is called. True, this is merely a comparison of two similar pieces of equipment, one with another, but in general both oscillators will not fail at the same time, and, since the frequency monitor is operating under nearly constant conditions with no load variations, it will therefore serve as a fairly reliable checking instrument (see Sec. 12.8).

12.5. Western Electric 1-kw. Broadcast Transmitter.—A schematic circuit arrangement of the W.E. 442A-1 (500-watt unit) or the W.E. 443A-1 (1,000-watt unit) broadcast transmitter together with complete power supply and relay system is shown in Fig. 12-3. (The 442A-1 is essentially the same as the 443A-1 except that the 442A-1 uses two instead of four 357A vacuum tubes in the modulating radio-frequency amplifier.) This transmitter incorporates the most modern advances in the broadcast-engineering field. The entire transmitter is alternating-current operated and does not use any motor generators for plate, bias, or filament power. All power circuits are automatically operated by relays and are suitably protected by overload circuit breakers and fuses. Door switches are provided for opening the high-voltage plate-supply circuit to protect against possible injury to the operator when adjustments or replacements are made necessary.

A front view of the transmitter with door closed is shown in Fig. 12-4. Large doors on both the front and rear swing open to expose all circuit components for adjustment and maintenance. A view with the front door open is shown in Fig. 12-5. All apparatus generating heat is placed near the top of the assembly. Control knobs located on either side of the

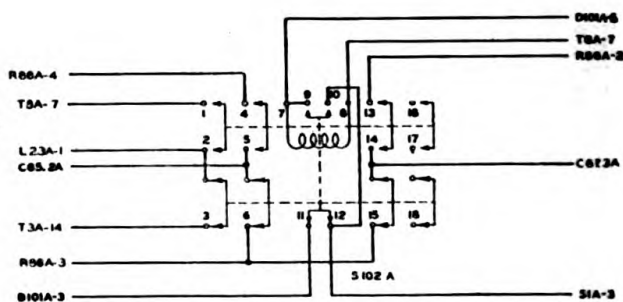
OTHERWISE SPECIFIED APPARATUS AND
 5 SHOWN IN BROKEN LINES ARE
 10, OMITTED, OR CHANGED DEPENDING
 15, FREQUENCY OF OPERATION.

10, FREQUENCY IS CHANGED AS INDICATED BY
 15, LINE IN THE 442A RADIO
 20, NG EQUIPMENT.

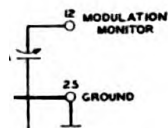
20, INCLUDED ONLY FOR OPERATION WITH
 25, INJECTED ANTENNA IF REQUIRED.

25, TRANSMITTING EQUIPMENTS, SERIAL
 30, TO 110 INCLUSIVE, C28A CONSISTS OF
 35, CTION VARIABLE CONDENSER.

35, CTION IS REMOVED IN THE 442A
 40, SMITTING EQUIPMENT.

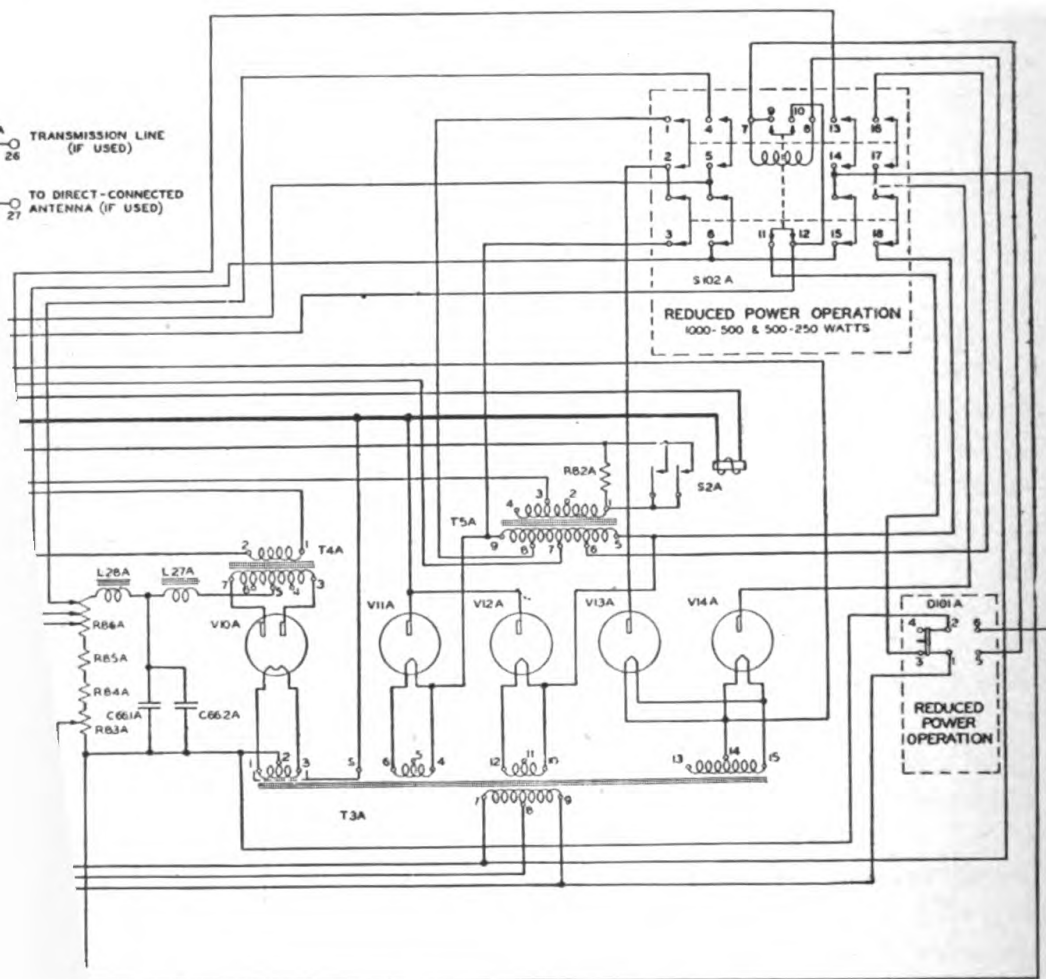


REDUCED POWER OPERATION
 1000 - 250 WATTS



26 TRANSMISSION LINE
 (IF USED)

27 TO DIRECT-CONNECTED
 ANTENNA (IF USED)



REDUCED POWER OPERATION
 1000 - 500 & 500 - 250 WATTS

REDUCED POWER
 OPERATION

front panel are protected against accidental operation by hinged doors, one of which is shown open.

1. **OSCILLATOR 702A HEATER CIRCUIT.**—Separate power-supply terminals are provided for the 702A oscillator-heater circuit. The primary connections of transformer T_6A should be connected according to the following table to accommodate the heater-input-supply voltage.

Heater-supply voltages.....	115	230
Primary connections.....	Parallel	Series
Terminal connections.....	$\begin{cases} 1 \text{ to } 3 \\ 2 \text{ to } 4 \end{cases}$	2 to 3
Input connections.....	$\begin{cases} 1 + 2 \\ \text{or equivalent} \end{cases}$	1 + 4

Switches D_9A and $D_{10}A$ in each line to the primary of transformer T_6A also serve as overload circuit breakers. In addition, combination switches and circuit breakers $D_{11}A$ and $D_{12}A$ provide individual overload protection and switching facilities for each of the two oscillators. Switches D_9A , $D_{10}A$, $D_{11}A$, and $D_{12}A$ should be closed after the oscillators are in position, and the oscillators should be allowed to reach their normal operating temperature of essentially 60°C . before final transmitter-tuning adjustments are made.

The magnetic circuit breakers used in this transmitter also serve as switches and bear the switch designation, such as D_1A , in the schematic diagram, Fig. 12-3. The power for the operation of the transmitter is controlled by power switch D_1A which also provides the necessary overload protection to the entire transmitter. Operation of this switch applies filament power to all tubes and energizes a pair of contacts on S_1A .

The manual regulator T_1A is provided to adjust the input voltage to the transmitter to 230 volts, as indicated by the power-supply voltmeter M_1A . Adjustments are made by means of the control designated **LOAD VOLTAGE**.

Switch D_5A provides overload protection to the bias-supply rectifier and, in case of an overload, also opens one side of the plate-rectifier-transformer primary circuit. Normally this switch should be left in the **ON** position.

Operation of bias switch D_2A energizes magnetic contactor S_1A which applies power to the bias rectifier and energizes the contacts of plate switch D_3A . Closing switch D_3A energizes the high-voltage rectifier transformer T_5A . The series coil of switch D_3A provides overload protection to the high-voltage rectifier while the trip coil, shunting $R_{34}A$, provides overload protection to the final radio-frequency stage tubes V_4A and V_5A . The alternating-current potential to the rectifier is first applied through resistor $R_{32}A$. After the rectifier output voltage reaches a predetermined value, relay S_2A operates and shorts the resistors. Surge-free starting

of the transmitter is accomplished by the use of this two-step-rectifier starting system.

The three door switches that are provided cause contactor S_1A to be deenergized when any one of the doors is opened. This removes all plate and bias potentials from the transmitter.

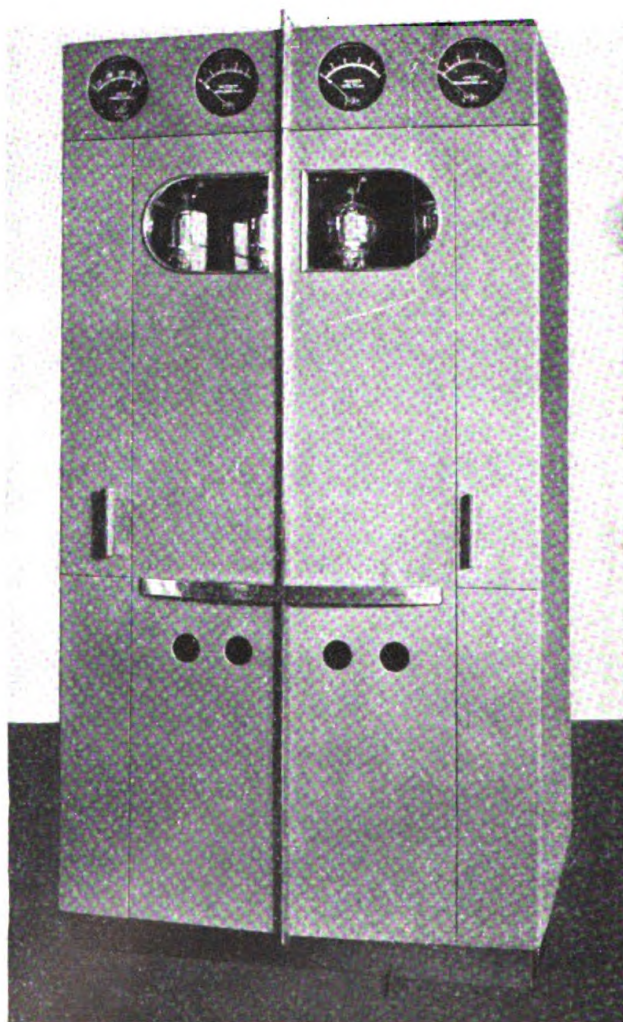


FIG. 12-4.—Western Electric broadcast transmitter 443A with front door closed.
(Courtesy of Western Electric Co.)

Only the final radio-frequency stage receives its bias from the bias rectifier. All other radio- and audio-frequency stages are self-biased.

Plate potential for the entire transmitter is obtained from a single-phase four-tube bridge-type rectifier that delivers current at both 1,750 and 3,500 volts. The 3,500-volt supply is used for the final radio-frequency stage, while the remaining radio- and audio-frequency tubes receive their plate and screen potentials from the 1,750-volt supply through either series resistors or from potentiometers. Taps 2, 3, and 4

are provided on the primary of the plate transformer to adjust for the required plate voltage.

2. RADIO-FREQUENCY CIRCUITS. *a. Oscillators.*—The carrier frequency of the transmitter is supplied by either one of two 702A oscillators which are mounted in the slide-rail assemblies in the front section of the vertical structure. All connections to the oscillator units are made by

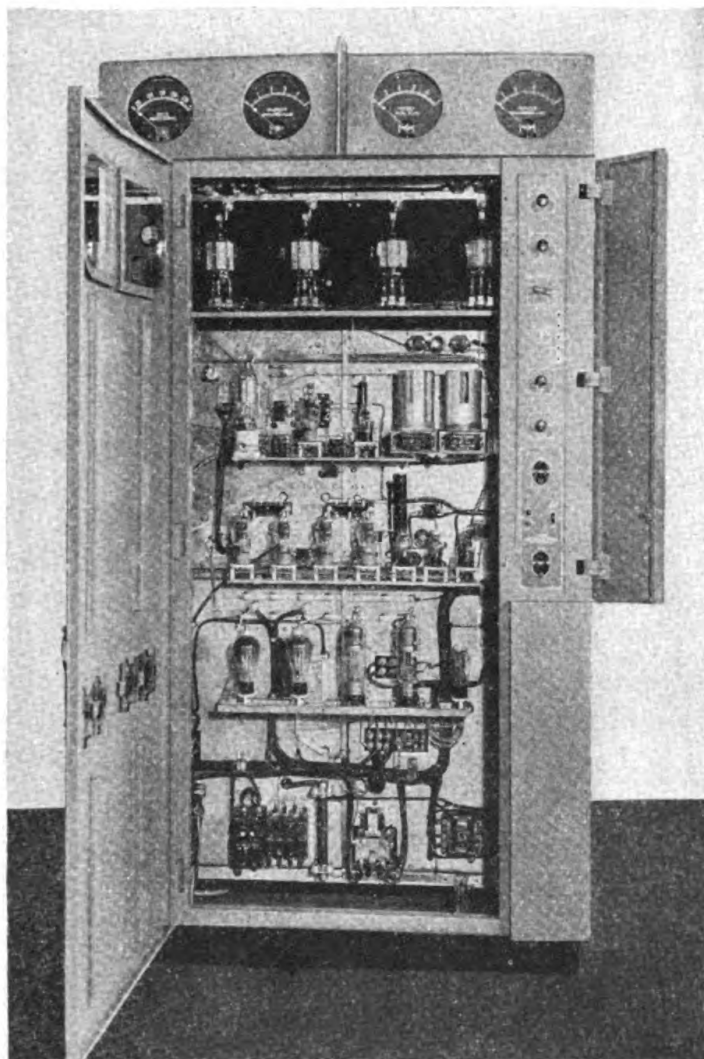


FIG. 12-5.—Western Electric broadcast transmitter 443A with front door and border panel open. (Courtesy of Western Electric Co.)

means of spring contacts which engage when the units are properly inserted.

Each oscillator contains the quartz crystal Y_1 , the vacuum tube V_1 , and associated circuits, and the temperature-control circuit consisting of the heater resistance R_6 and thermostat TD_1 . Each of the 702A oscillators is adjusted as a unit to the operating frequency and will maintain its calibration well within ± 10 cycles.

The radio-frequency output obtained from terminal 3 of each oscillator is connected to switch $D_{14}A$, which permits connecting either oscillator

to the grid circuit of the first amplifier tube. Plate supply for the oscillator is also connected through this switch and is obtained from a slider on resistance $R_{77}A$. Switch $D_{14}A$ and the associated control knob are located directly below the oscillator slide-rail assembly. The line on the knob points to the oscillator that is selected. A single Western Electric 247A tube is used in each oscillator.

b. First Radio-frequency Amplifier Stage.—The radio-frequency input voltage to the first amplifier tube V_1A (Western Electric 349A tube) is impressed across resistance R_3A . The gain of this stage, and thus the output to the transmitter, is controlled by changing the setting of the R.F. output control R_1A which varies the bias voltage applied to the grid of V_1A through resistances R_2A and R_3A . The potential drop in R_1A is obtained from two sliders on $R_{76}A$. The plate of V_1A works into the anti-resonant circuit, consisting of the inductance L_1A in parallel with the variable condenser C_7A , which is tuned by the control designated plate V_1 . Condenser C_6A serves as a plate-blocking condenser only. The plate potential for V_1A is supplied through tuning coil L_1A and resistance R_7A from a slider on resistance $R_{77}A$. Screen potential is obtained from the same slider on $R_{77}A$ through resistance R_6A . Plate current of V_1A is measured by the potential drop across resistance R_5A and is indicated by test meter M_2A when the test-meter switch D_3A is in the P. $V1 \times 20$ position. Plate current, as measured in this equipment, indicates the total current from the tube cathode, a portion of which may flow to other elements of the tube than the plate, such as the grid and screen.

Transmission-line protection is provided by the circuit composed of S_3A , C_1A , and R_2A . Should lightning produce an arc in the transmission line, relay S_3A will operate and change the bias on V_1A to below cutoff, thereby reducing the carrier to zero. The arc is therefore extinguished and relay S_3A is released, restoring the normal bias to V_1A , and therefore the carrier output, at a rate governed by the R_2A - C_1A circuit.

c. Second Radio-frequency Amplifier Stage.—The output of V_1A is coupled to the grid circuit of the second amplifier tube V_2A (Western Electric 350A tube) through condenser C_6A . Resistances R_8A^1 and R_9A provide a grid load and path for the negative bias which is obtained by the potential drop in resistances $R_{11}A^1$ and $R_{12}A$, between cathode and ground. Grid current in this tube is indicated by the potential drop across R_8A and is obtained with the Test-Meter switch in the G. $V2 \times 20$ position. Total space current is indicated by the potential drop in $R_{11}A$ and is obtained with the test-meter switch in the P. $V2 \times 100$ position. The plate of V_2A works into the anti-resonant circuit consisting of the inductance L_2A in parallel with the variable condenser $C_{12}A$ which is tuned by the control designated Plate V_2 .

¹ Resistances R_8A , $R_{11}A$, $R_{12}A$, and $R_{13}A$ are meter shunts of negligible resistance.

Screen potential for V_2A is obtained through $R_{13}A$ from a slider on $R_{77}A$. The plate potential is obtained from a slider on $R_{78}A$ through $R_{14}A$, $L_{34}A$, L_2A , and $L_{30}A$.

The tuned output circuit of V_2A is built out to provide the neutralizing potential for V_3A through $C_{22}A$.

d. Third Radio-frequency Amplifier Stage.—The output of V_2A is coupled to the grid circuit of the third amplifier tube V_3A (Western Electric 331A tube) through condenser $C_{12}A$. Resistances $R_{15}A$ and $R_{16}A$ provide a grid load and path for the negative bias which is obtained by the potential drop in the resistances $R_{18}A$ and $R_{19}A$ between cathode and ground. Grid current in this tube is indicated by the potential drop across $R_{15}A$ and is obtained with the test-meter switch in the G. $V3 \times 20$ position. Total space current is indicated by the potential drop across $R_{18}A$ and is obtained with the test-meter switch in the P. $V3 \times 200$ position. The plate of V_3A works into the tuned transformer L_3A . The tuning is accomplished by the variable air condenser $C_{19}A$, the control of which is designated plate V_3 . The coupling of this transformer is varied by the control designated output coupling V_3 . A tap on the primary of L_3A provides a connection through condenser $C_{17}A$ and terminal 11 for a radio-frequency monitoring circuit.

*e. Fourth Radio-frequency Amplifier Stage.*¹—Throughout this text, when referring to the fourth radio-frequency stage tubes, the singular designations V_4A and V_5A will be used whether one or two tubes are used in each circuit position. Each designation signifies two Western Electric 357A tubes in the 1,000-watt transmitter 443A-1 and one Western Electric 357A tube in the 500-watt transmitter 442A-1.

The secondary of L_3A couples the output of V_3A directly to the grid circuit of V_5A and through the intergrid coupling condenser $C_{23}A$ to the grid circuit of V_4A . This intergrid condenser in conjunction with L_8A , $C_{37}A$, and grid load resistance $R_{27.1}A$ and $R_{27.2}A$ provide the required circuits to obtain the 90-degree phase relationship between V_4A and V_5A . Condenser $C_{33}A$ and coil L_4A provide a means of tuning the rotor output of L_3A to resonance. The grid circuit of V_5A is loaded by resistance $R_{28}A$. The sampling circuits $C_{71}A$, $C_{72}A$, $C_{73}A$, $L_{26}A$ and $C_{74}A$, $C_{75}A$, $C_{76}A$, $L_{26}A$ permit checking the phases of the grid voltages on the tubes by connecting a cathode-ray oscilloscope at jacks J_1A and J_2A .

Individual fixed-bias potentials are fed through the windings of audio-input choke $L_{29}A$ and radio-frequency coils L_8A , L_4A and the rotor of L_3A to the grids of V_4A and V_5A . Modulation is achieved by impressing the audio voltage upon the grids of these tubes through the same radio-

¹ This amplifier employs the Doherty high-efficiency amplifier circuit, which is explained in Sec. 4.22.

frequency coils. The lower ends of the radio-frequency grid-input circuits to V_4A and V_5A are made common through condensers $C_{53}A$ and $C_{54}A$. $C_{24}A$ and L_5A provide a series resonant radio-frequency by-pass circuit which presents a high impedance to the audio-frequency modulating voltages.

The output circuit of V_4A contains neutralizing transformer L_9A , which, in conjunction with $C_{38}A$, provides the neutralizing voltage for V_4A . A similar transformer $L_{12}A$ is used in conjunction with $C_{27}A$ to neutralize V_5A . Plate power is fed through $L_{14}A$ and the primary of $L_{12}A$ to V_5A . The plate of this tube is then connected to the plate of V_4A , for both direct-current and radio-frequency energy, through interplate coil $L_{16}A$. By means of variable air condensers $C_{40}A$ and $C_{30}A$, the output circuits of V_4A and V_5A , respectively, are adjusted. The sampling circuits $C_{80}A$, $C_{81}A$, $C_{82}A$, $L_{18}A$ and $C_{77}A$, $C_{78}A$, $C_{79}A$, $L_{13}A$ permit checking the phases of the plate voltages on the tubes by connecting a cathode-ray oscilloscope at jacks J_3A and J_4A .

Test-meter multiplier resistors $R_{22}A$, $R_{23}A$, $R_{24}A$, $R_{31}A$, $R_{32}A$, and $R_{33}A$ in conjunction with test-meter switch D_8A and meter M_2A permit reading the individual cathode currents as well as the parallel currents of the output circuit tubes. Meter M_4A indicates the total plate current of these tubes.

The radio-frequency output is fed through $L_{15}A$, the harmonic suppression circuit composed of $C_{42}A$ and $L_{19}A$, the antenna or transmission-line coupling circuit composed of $C_{43}A$ and $L_{20}A$ and meter M_5A to either an antenna or a transmission line. A sample of the radio-frequency output of the transmitter is obtained through the R.F. monitor condenser $C_{44}A$ for modulation monitoring purposes.

3. AUDIO AMPLIFIER.—The amplifier which provides the necessary audio-frequency modulating voltage has two resistance-coupled stages employing tube V_8A (Western Electric 349A tube) in the first stage and tubes $V_{9.1}A$, $V_{9.2}A$, $V_{9.3}A$ and $V_{9.4}A$ (four Western Electric 350A tubes) in parallel in the second stage. The input to the first stage is the difference of two voltages, one the signal from the speech-input equipment through the input transformer T_7A effectively across $R_{41}A$, the other a portion of the signal fed back from the output of the transmitter through $C_{85}A$, demodulated by the half-wave rectifier tube V_7A (Western Electric 351A tube), and applied in series with the speech input voltage, through $C_{45}A$, $R_{39}A$ and $R_{40}A$ to ground. The grid bias of V_8A is obtained by means of self-biasing resistance $R_{43}A$. The parallel tubes V_9A of the second stage obtain their bias from the common self-biasing resistance $R_{60}A$. Each tube space current is measured by the drop across meter shunts $R_{44}A$, $R_{56}A$, $R_{57}A$, $R_{58}A$, and $R_{59}A$ that are connected in the cathode circuits of the tubes. The output of V_9A is connected to the grids of V_4A and V_5A through $C_{53}A$ and $C_{54}A$. The audio voltage to

V_{4A} is fed through L_{3A} and to V_{5A} through the rotor of L_{3A} and coil L_{4A} .

The radio-frequency rectifier tube V_{5A} (Western Electric 351A tube), associated with the audio-output transformer T_{3A} , furnishes a means of audio-frequency monitoring by rectifying a portion of the power-amplifier output.

4. FIRST RADIO-FREQUENCY AMPLIFIER TUNING.—Resonance is obtained in all plate circuits by adjustment for minimum direct-current plate current of the tube whose tuned output circuit is being adjusted. In tuning any of the radio-frequency circuits, care should be taken that no circuit is tuned to the second harmonic of the fundamental frequency. Should two points of resonance be found with the coil setting specified, the one at which the capacitance of the variable condenser is maximum is the correct adjustment. This will correspond to the point of higher dial reading and higher output current.

Before applying plate voltage, open link switch D_{4A} (located above and between $V_{4.1A}$ and $V_{5.1A}$). The link of this switch consists of two plugs with a flexible interconnection. When the plugs are inserted into the associated insulated jacks, the circuit is closed.

Caution: When switch D_{4A} is open and the plate rectifier switch is opened, the condition of charge of the high-voltage condensers should be observed on the amplifier-plate meter before working on any apparatus. The front door of the unit should be left open when working on apparatus in the back section. Opening of the front door establishes a ground on the high-voltage circuit by means of switch D_{17A} . These safety measures are advised for the protection of operating personnel in addition to the safety devices that are provided within the transmitter.

Close switch D_{5A} , place the test-meter switch in the P. $V_1 \times 20$ position, and apply bias and plate power by means of the bias and plate switches. With the R.F. output control set at about 90 adjust the plate V_1 tuning control until the test meter indicates a minimum or until the test meter indicates a maximum when the test-meter switch is turned to the G. $V_2 \times 20$ position.

5. SECOND RADIO-FREQUENCY AMPLIFIER TUNING.—Place the test-meter switch in the P. $V_2 \times 100$ position, and adjust the plate V_2 tuning control until the test meter indicates a minimum or until the test meter indicates a maximum when the test-meter switch is turned to the G. $V_3 \times 20$ position. The third radio-frequency stage should be tuned immediately after the tuning of the second stage is completed or the R.F. output control should be turned to zero to prevent excess dissipation in the plate of the third stage.

6. THIRD RADIO-FREQUENCY AMPLIFIER TUNING.—Before tuning this amplifier, the tap on the primary of L_{3A} that is associated with condenser C_{17A} and terminal 11 should be disconnected. The adjustment of this

tap is covered under the heading Adjustment of Radio-frequency Monitor Voltage Tap. With the output-coupling V_3 control set at zero¹ and the test-meter switch in the P. $V_3 \times 200$ position, adjust the plate V_2 tuning control until the test meter indicates a minimum.

7. RADIO-FREQUENCY BY-PASS TUNING.—Remove the plate and grid power, and connect the test clip associated with $C_{33}A$ and the test jack to the front connector of $C_{33}A$. With the sweep circuit of the cathode-ray oscilloscope in operation, connect the vertical plates to the test jack and apply grid and plate power. With the output-coupling V_3 control set at approximately 50, adjust the R.F. by-pass tuning control for a minimum deflection on the cathode-ray oscilloscope. The deflection increases rapidly when turning the control to either side of the minimum position. Care must therefore be exercised in tuning this circuit. If the cathode ray indicates a number of lines or images instead of a single rectangle, it is an indication of rectified grid current in the final radio-frequency stage. This rectification produces radio-frequency harmonics which appear as secondary lines or images in the oscilloscope. The setting of the R.F. output control should be reduced until the secondary images or lines are eliminated before completing the adjustment of the R.F. by-pass tuning control.

8. FOURTH RADIO-FREQUENCY AMPLIFIER GRID-INPUT CIRCUIT TUNING.—In the tuning of this circuit, the intergrid coupling and grid V_4 control settings govern the phase relation of the grid input voltages while the grid V_5 control is used to tune the rotor output circuit to resonance. An approximate setting of the intergrid-coupling control should first be in accordance with Fig. 12-4. Thereafter all preliminary adjustments of the phase relation of the two grid voltages should be made with the grid V_4 control. With the grid and plate power on and the output-coupling V_3 control set at approximately 10, observe the phase relation of the grid voltages of V_4A and V_5A on a cathode-ray oscilloscope whose two pairs of plates are connected to the grid V_4 and grid V_5 jacks. A 90-degree relation is indicated by an elliptical pattern with the axes of the ellipse horizontal and vertical. The phase may be varied by adjusting the grid V_4 control. If a 90-degree relation is not obtained at any setting of the grid V_4 control, the active turns on L_3A should be changed. If the best tuning is obtained with the grid V_4 control at minimum, the number of active turns in L_3A should be reduced; if the maximum setting gives the best tuning, the active turns of L_3A should be increased. The final

¹ For zero coupling, the mechanical axis of the rotor L_2A should be at essentially 90 degrees to the stator when the output coupling V_3 control is set at zero. The electrical zero can be determined after the transmitter has been adjusted for essentially the normal carrier output. Turning the output coupling V_3 control to zero should reduce the total plate or R.F. output meter readings to zero. The mechanical linkage should be readjusted if zero coupling cannot be obtained.

adjustment of the grid V_4 control should be as near to zero as the turn adjustment of L_3A will permit.

Inspection of the cathode-ray pattern is ordinarily facilitated if the taps on the sampling coils and the associated stacked condensers are adjusted to give a somewhat greater vertical than horizontal deflection. The vertical and horizontal deflection should be kept within $1\frac{1}{4}$ and $\frac{3}{4}$ in., respectively.

After the grids have been properly phased, adjust the grid V_5 control for a maximum indication on the test meter when the test-meter switch

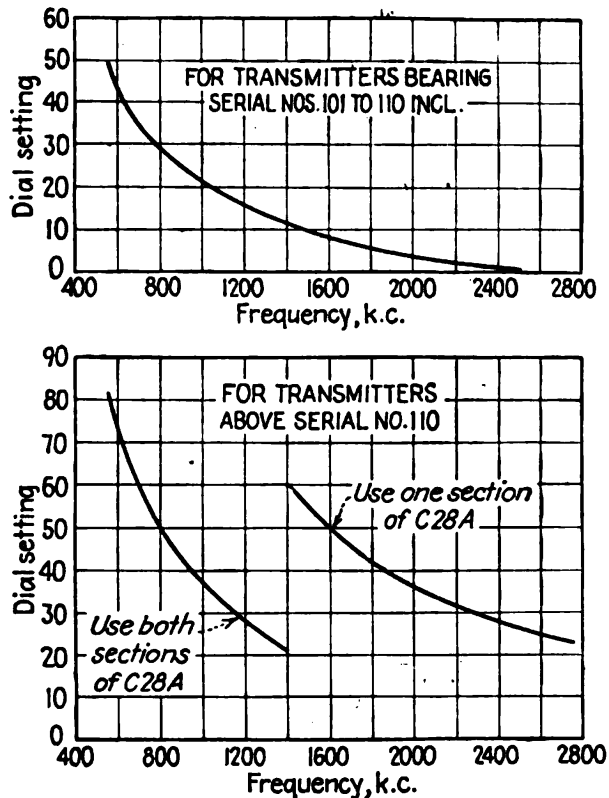


FIG. 12-6.—Tuning chart for condenser $C_{28}A$ in 443A transmitter.

is in the $P. V_3 \times 200$ position. Although this maximum deflection is not great, it is adequate for tuning purposes.

During the procedure of adjusting the phasing of the grid circuits, it will be necessary to increase the setting of the output-coupling V_3 control. Adjustments of the grid V_5 control should, however, be made with just sufficient coupling to give a noticeable deflection on the test meter.

The grid-phase relation is somewhat affected by the position of the output-coupling V_3 control, making it necessary to check the phase relation whenever the coupling control is changed.

9. FOURTH RADIO-FREQUENCY AMPLIFIER OUTPUT-CIRCUIT TUNING (Bridge Method).—The most desirable method of tuning the fourth radio-frequency amplifier output circuit is by means of a radio-frequency bridge. If, however, the series components, resistance, and reactance

of the circuit into which the transmitter is to operate are definitely known, the transmitter can be tuned without the use of a bridge. The bridge method will be described first and should be used when possible. The method of tuning without a bridge will be covered later. All other parts of these instructions are common to both methods of tuning.

Before proceeding with the adjustment of the fourth R.F. amplifier output circuit, it is necessary that the radio-frequency transmission line be connected to the antenna system through suitable coupling equipment, adjusted to terminate the line in its characteristic impedance of essentially 65 ohms. No information on this adjustment is included herein.

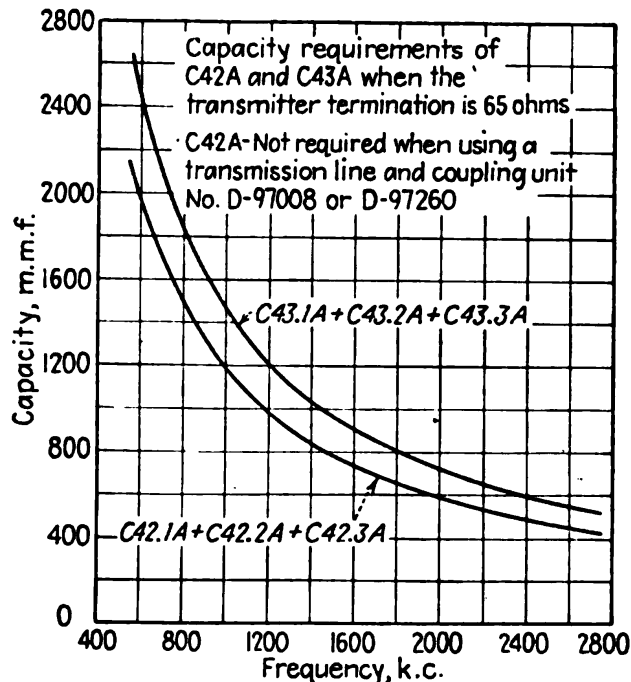


FIG. 12-7.—Tuning chart for condenser $C_{42}A$ and $C_{43}A$ in 443A transmitter.

Condenser $C_{42}A$ is not used when the transmitter is connected through a transmission line to either a D-97008 or a D-97260 antenna-coupling unit. With the transmission line properly terminated and connected to the transmitter, the adjustments of $L_{20}A$ and $C_{43}A$ are made with the use of a radio-frequency bridge arranged for measuring series components of grounded impedances. The slider on $L_{19}A$ should be opened and the bridge connected to the junction of $C_{43}A$ and $L_{20}A$. The capacity of $C_{43}A$ should be adjusted as near to the value indicated on Fig. 12-7 as possible. Figure 12-8 indicates the approximate turns required for $L_{19}A$ and $L_{20}A$. Coil $L_{20}A$ should then be adjusted until the bridge indicates a resistance of 90 to 110 ohms and a negative reactance of 150 to 250 ohms. The bridge should then be connected to the junction of $L_{19}A$ and $L_{15}A$. Open the slider on $L_{15}A$ and adjust the slider on $L_{19}A$ until the reactive component is reduced to essentially zero, the resistive component remaining 90 to 110 ohms.

Condensers $C_{42}A$ and $C_{43}A$ are used for all other conditions of operation and should be set in accordance with Fig. 12-7. The approximate turns required for $L_{19}A$ and $L_{20}A$ are shown in Fig. 12-8. The procedure for adjusting $L_{19}A$ and $L_{20}A$ is similar to the foregoing except that $L_{20}A$ is adjusted for a resistance of 65 to 75 ohms with a negative reactance of 150 to 250 ohms. The adjustment of $L_{19}A$ is the same as before.

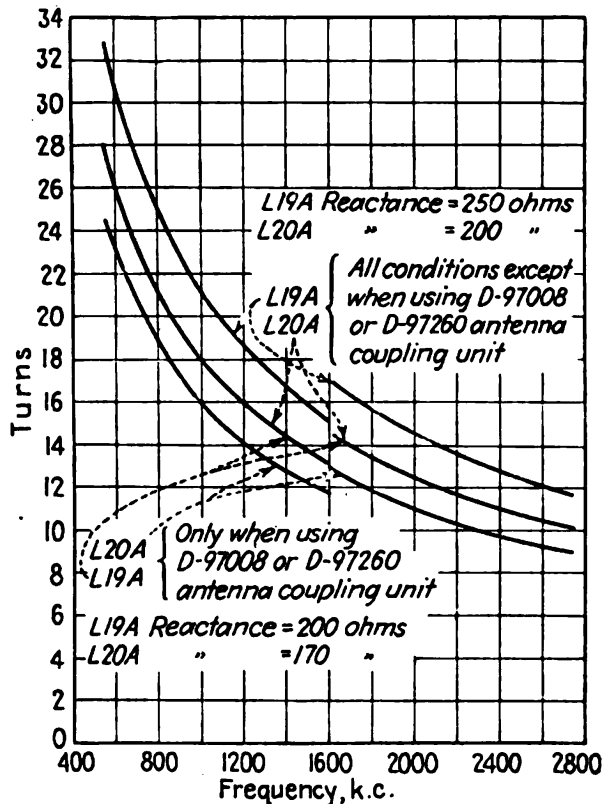


FIG. 12-8.—Tuning chart for coils $L_{19}A$ and $L_{20}A$ in 443A transmitter.

10. ADJUSTMENT OF LOAD (PLATE CIRCUIT) IMPEDANCES (Bridge Method).—This consists in finding the proper tap on coil $L_{15}A$ to give the desired load impedance for the combined output of V_4A and V_5A and then the proper tap on coil $L_{16}A$ to give the desired load impedance for V_4A when V_4A is supplying the smaller instantaneous outputs without assistance from V_5A . The impedance values should be approximately as shown below:

Transmitter	V_5A impedance, ohms	V_4A impedance, ohms	$L_{16}A$ reactance, ohms
442A—500 watts	2,000	8,000	4,000
443A—1,000 watts	1,000	4,000	2,000

The adjustment of the load impedances should be carried out with all the filament power off and the neutralizing V_4 and neutralizing V_5 controls set at approximately 20.

Set the sliders on L_9A and $L_{12}A$ to include all the turns in the circuits and the slider on coil $L_{15}A$ in accordance with Table 2 (which appears in manufacturer's instruction book). A temporary ground should be placed on the plate circuit of V_4A . By means of the radio-frequency bridge, arranged to measure parallel components of grounded impedances, measure the parallel resistance between the plate of V_5A and ground at the carrier frequency. This parallel resistance is controlled entirely by the reactance of coil $L_{15}A$ and by the introduced resistance as determined by the transmission-line coupling circuit and also the harmonic suppression circuit when the latter is used. Coil $L_{13}A$ should be adjusted to give a value for the plate-to-ground resistance according to the foregoing table. Increasing the number of turns on $L_{15}A$ increases the parallel resistance, and vice versa. If it is impossible to secure the value of parallel resistance given in the table by adjusting $L_{15}A$, a change in the introduced resistance by adjustment of $L_{19}A$ and $L_{20}A$ must be made. Increasing the introduced resistance lowers the parallel resistance, and vice versa.

Upon completion of the adjustment of coil $L_{15}A$, the plate V_5 control should be adjusted until the impedance is purely resistance. The parallel resistance will not change when the control is adjusted. Link $D_{16}A$ permits changing the range of variable air condenser $C_{30}A$. Links $D_{18}A$ and $D_{19}A$ are provided to connect condensers $C_{31.1}A$ and $C_{31.2}A$ in parallel with $C_{30}A$.

An alternative method of using the radio-frequency bridge for adjusting the plate impedance is to use the substitution method. The bridge should first be adjusted for a balance when a resistance whose ohmic value is equal to the desired plate impedance is connected to the bridge. The resistance should be located very near to the point on the circuit where the bridge will be connected to avoid a change in lead capacity and inductance when changing the connector from the resistance to the circuit. After the bridge has been balanced, the connector should be transferred to the circuit and $L_{15}A$ and the plate V_5 control adjusted until the bridge indicates a balance. This balance indicates that the desired parallel resistance and zero reactance have been obtained. The main advantages of this method are that the bridge has to be balanced only once and resistance calculations do not have to be made. A metalized resistance (IRC) is satisfactory for this substitution method.

Next remove the temporary ground from the plate of V_4A and connect the bridge to measure the parallel impedance between the plate of V_4A and ground. Either of the foregoing methods of bridge measuring can be used. The parallel resistance at this point is controlled entirely by

the reactance of coil $L_{16}A$, which should be adjusted to give a value according to the preceding table. In case it is necessary to readjust $L_{16}A$ by more than four turns, the previously described adjustment of the plate V_3 control should be repeated to secure zero reactance, and then recheck the parallel resistance from the plate of V_4A to ground, making any further slight readjustments of $L_{16}A$ that may be required to secure the desired parallel resistance value. The plate V_4 control should be adjusted until the parallel impedance is purely resistive. Link $D_{20}A$ is provided to change the range of condenser $C_{40}A$ which is associated with the plate V_4 control. If, when the plate V_4 control is at minimum, the bridge-balancing procedure indicates that the capacity of $C_{40}A$ is too high, link $D_{20}A$ should be opened. If this reduction in capacity is not sufficient, the number of active turns on L_9A should be reduced turn by turn until a balance can be obtained by adjusting the plate V_4 control. The final adjustment of the plate V_4 control should be as near to zero as the tap adjustment on L_9A will permit. Adjustment of this coil has no effect upon the parallel resistance.

11. TUNING OF THE FOURTH RADIO-FREQUENCY AMPLIFIER OUTPUT CIRCUIT (Without Bridge).—The following tuning procedure is based upon operating the transmitter into a known transmission line or antenna. All tables and figures are calculated for operating the transmitter into a circuit having a series resistance of 65 ohms and reactance not greater than ± 20 ohms. The coils and condensers should first be set in accordance with tables and graphs.

Since two sets of curves are provided for $L_{19}A$ and $L_{20}A$, care should be taken to use the correct set for the particular installation in question. If the series reactance of the transmission line or antenna input is greater than ± 20 ohms, the turns on $L_{20}A$ should be changed to compensate for this reactance. The combined reactance of $L_{20}A$ and the transmission line or antenna input should be equal to the values listed for $L_{20}A$ in the figures. If the circuit into which the transmitter operates has a positive reactance, the reactance of $L_{20}A$ should be reduced by that amount and the inductance calculated by the formula $L = 159.2X_L/f$, where L is the inductance of $L_{20}A$ in microhenrys, X_L the new value of reactance of $L_{20}A$ in ohms, and f the frequency in kilocycles. The proper turns for $L_{20}A$ can then be obtained from Fig. 12-9. If the circuit into which the

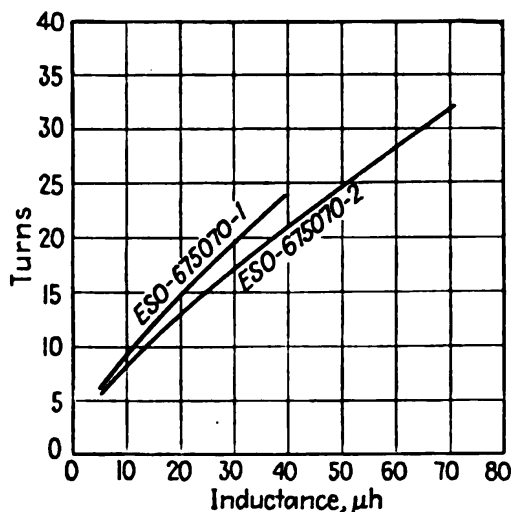


FIG. 12-9.—Inductance charts for coil $L_{20}A$ in 443A transmitter.

circuit into which the transmitter operates has a positive reactance, the reactance of $L_{20}A$ should be reduced by that amount and the inductance calculated by the formula $L = 159.2X_L/f$, where L is the inductance of $L_{20}A$ in microhenrys, X_L the new value of reactance of $L_{20}A$ in ohms, and f the frequency in kilocycles. The proper turns for $L_{20}A$ can then be obtained from Fig. 12-9. If the circuit into which the

transmitter operates has a negative reactance, the reactance of L_{20A} should be increased by that amount and the new value of inductance and turns should be obtained as outlined above.

After all coils and condensers have been adjusted according to the preceding paragraph, the fourth radio-frequency amplifier should be neutralized.

12. OPERATION INTO OTHER THAN 65-OHM ANTENNA OR TRANSMISSION LINE.—The instructions for tuning the output circuit of the 442A-1 and 443A-1 radio-transmitting equipments assume that the transmitter is

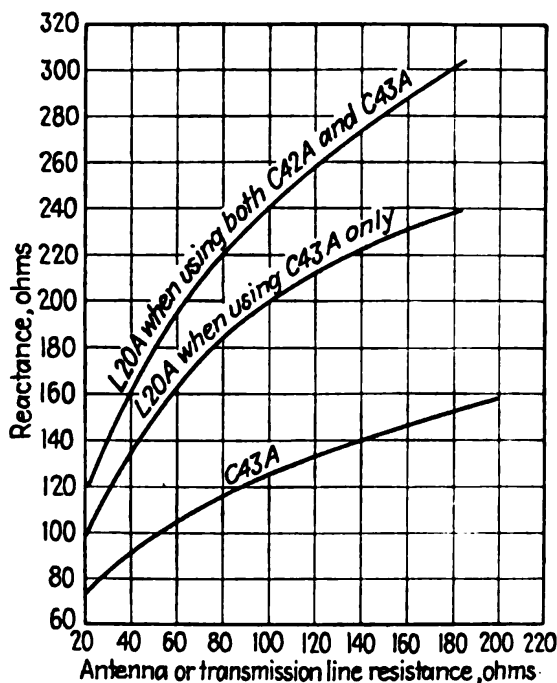


FIG. 12-10.—Tuning chart for coils L_{20A} and C_{43A} in 443A transmitter.

to work into a load impedance having a resistance component of 65 ohms. If this is not the case, refer to the following.

If the transmitter is to work into an impedance having a resistance component other than 65 ohms, obtain the required value of reactance of C_{43A} from Fig. 12-10; then compute the capacity from the formula

$$C = \frac{159.2 \times 10^6}{fX_c}$$

where f is in kilocycles.

X_c is in ohms.

C is in micromicrofarads.

Obtain the required value of reactance of L_{20A} from Fig. 12-10, and compute the inductance from the formula

$$L = \frac{159.2X_L}{f}$$

where X_L is in ohms.

f is in kilocycles.

L is in microhenrys.

From this value of inductance, the number of turns for $L_{20}A$ may be obtained from Fig. 12-9.

Note: Either of two coils may be furnished for position $L_{20}A$, depending on antenna characteristics and frequency. Figure 12-9 shows the inductance-turns relation for both, and the correct curve should be selected by referring to the tag marking on the coil furnished.

If the load impedance (antenna or transmission line) has a reactance component exceeding ± 10 ohms, $L_{20}A$ must be further adjusted. In such a case, the reactance indicated in Fig. 12-10 for $L_{20}A$ is actually the combined reactance of the load and coil $L_{20}A$, and the correct reactance of the coil may be obtained by subtracting (if positive) or adding (if negative) the load reactance and the combined reactance indicated for $L_{20}A$ in Fig. 12-10. The inductance and number of turns may then be obtained from the formula and Fig. 12-9 as described above.

Note: If a direct-connected antenna has a positive reactance exceeding 100 ohms, series condenser $C_{85}A$ is supplied and its reactance must be subtracted from the antenna reactance to give the load reactance referred to above.

The adjustment of $C_{43}A$ is independent of the load reactance, depending only on the load resistance.

13. ADJUSTMENT OF PLATE IMPEDANCE OF V_5A .—Temporarily ground the radio-frequency output circuit of V_4A by placing a connector across $C_{40}A$ or some equivalent position of the circuit. Disconnect the grid and plate connections of V_4A from the circuit by removing the plugs from the associated jacks that are located directly behind the tubes.

Short-circuit condenser $C_{37}A$ by means of a connector from the stator to the rotor. Disconnect the lead from terminal 1 of plate-retard coil $L_{23}A$, and place a temporary connection from this terminal to terminal 7 of T_5A . In this manner, the voltage of V_5A is reduced to 1,750 volts as indicated by the amplifier-plate meter. The lead that is removed from $L_{23}A$ should be suspended clear of all grounds since it is at 3,500 volts above the ground when the rectifier is in operation.

Set the controls of $C_{85}A$ and $R_{39}A$ at zero. With switch D_4A closed and the R.F. output control set at zero, apply grid and plate power. Increase the excitation on the grids of V_5A by adjusting the R.F. output control in conjunction with the output-coupling V_3 control until the total-plate-current meter reads about 0.3 amp. for the 443A-1 radio-transmitting equipment or 0.15 amp. for the 442A-1 radio-transmitting equipment. The plate V_5 control should then be adjusted for a minimum indication on the total-plate meter. The effective range of the tuning capacities, variable and fixed, of that circuit can be changed by

means of links $D_{16}A$, $D_{18}A$, and $D_{19}A$. After the circuit has been tuned for a minimum plate current, the radio-frequency output should be increased to 0.6 ± 0.1 of the normal carrier power. The plate efficiency should then be 56 ± 2 per cent as calculated by the formula $(I_{ant.})^2 \times R_{ant.}/E_p I_p$. If the efficiency is higher than 58 per cent, the number of active turns on $L_{15}A$ should be reduced and the circuit returned for minimum plate current. If the efficiency is too low, the number of turns on $L_{15}A$ should be increased and the circuit retuned for minimum plate current. This procedure should be followed until the required efficiency is obtained. After the output circuit of V_5A is properly adjusted, remove the temporary connectors from condensers $C_{37}A$ and $C_{40}A$. The normal high-voltage rectifier circuit should be restored by removing the temporary connector from terminal 7 of T_5A and terminal 1 of retard coil $L_{22}A$ and reconnecting the 3,500-volt lead to this retard-coil terminal. The normal grid and plate connections of V_4A should be restored by inserting the plugs into their associated jacks.

14. ADJUSTMENT OF PLATE IMPEDANCE OF V_4A .—Disconnect the grid and plate connections of V_5A from the circuit by removing the plugs from the associated jacks that are located directly behind the tubes. With the R.F. output control set at zero, apply grid and plate power. Increase the excitation on the grids of V_4A by adjusting the R.F. output control in conjunction with the output-coupling V_3 control until the total-plate-current meter reads about 0.2 amp. for the 443A-1 radio-transmitting equipment or 0.1 amp. for the 442A-1 radio-transmitting equipment. The plate V_4 control should then be adjusted for a minimum indication on the total-plate meter. Link $D_{20}A$ is provided to change the range of condenser $C_{40}A$ which is associated with the plate V_4 control. If the tuning procedure indicates that the capacity of $C_{40}A$ is too high when link $D_{20}A$ is opened, it will be necessary to reduce the number of active turns on L_9A . Adjustment of this coil does not affect the plate impedance of V_4A but affects the value of capacity required to tune that circuit. After the circuit has been tuned for a minimum plate current, the radio-frequency output should be increased to 0.6 ± 0.1 of the normal carrier power. If the plate efficiency is then other than 62 ± 1 per cent, the turns on $L_{16}A$ should be changed. They should be increased if the efficiency is too low or decreased if too high. Each time such a change is made, the plate V_4 control should be readjusted for minimum plate current. The final adjustment of the plate V_4 control should be as near to zero as the tap adjustment on L_9A will permit. After this circuit is adjusted for the proper efficiency, the normal grid and plate connections of V_5A should be restored by inserting the plugs into their associated jacks. The procedure outlined under the heading Final Tuning of the Fourth Radio-frequency Stage should then be followed.

15. **NEUTRALIZING OF THE FOURTH RADIO-FREQUENCY AMPLIFIER.**—Neutralizing of this amplifier is accomplished by using a cathode-ray oscilloscope as a voltage indicator and adjusting the neutralizing control for a minimum deflection on the cathode-ray tube. The plate of the tube not being neutralized should be grounded with a temporary connection. The lead provided on the test jack should be clipped to the plate of the tube to be neutralized.

If the oscilloscope employed has no radio-frequency by-pass to ground, it is suggested that a 0.005-mf. condenser be connected between the common point of the vertical and horizontal plates and ground. This establishes a definite 90-degree relationship between the axes of the pattern.

To neutralize V_4A , connect the test jack to the plate of V_4A by means of the test clip and place a temporary ground on the plate of V_5A . Plug the lead from the vertical plates of the cathode-ray oscilloscope in the test jack. With switch D_4A open, apply grid and plate power and adjust the neutralizing V_4 control for a minimum indication on the cathode-ray oscilloscope. If secondary lines or images appear, it is an indication of rectified grid current in the fourth stage. The R.F. output control should be turned toward zero until these lines disappear in the cathode-ray oscilloscope before completing the adjustment of the neutralizing V_4 control.

The neutralizing procedure for V_5A is identical to the above except that the plate of V_4A is grounded, the test clip is connected to the plate of V_5A , and the neutralizing V_5A control is adjusted for a minimum deflection on the cathode-ray oscilloscope. If the initial deflection on the cathode-ray tube is too small, temporarily ground the junction of $L_{15}A$ and $L_{19}A$. Upon completion, remove the temporary grounds and close switch D_4A .

16. **FINAL TUNING OF THE FOURTH RADIO-FREQUENCY STAGE.**—Set the controls of $C_{85}A$ and $R_{39}A$ at zero. With the R.F. output control set at 80 and the output-coupling V_8 control at zero, apply power by means of the grid and plate switches. Slowly increase the excitation of the final stage by turning the output-coupling V_8 control clockwise until the total plate current is about equal to the value given in Table 5 (which appears in manufacturer's instruction book) for the normal carrier output power. Check the 90-degree grid circuit relation, making a readjustment of the grid V_4 control if necessary. Next observe the phase relation of the plate potentials of the two tubes, using the plate V_4 and plate V_5 jacks, and adjust the plate V_5 control for a 90-degree phase difference. This is the only control that affects the relative phases of the plate potentials. The plate V_4 control should then be adjusted for a straight line pattern in the cathode-ray oscilloscope when the horizontal and vertical plates are connected to the plate V_4 and grid V_4 jacks. This

indicates a pure phase reversal in the tube, that is, the plate load impedance is a pure resistance. This should correspond very nearly with minimum V_4A plate current. With the two grid potentials 90 degrees apart and the two plate potentials 90 degrees apart, and with a pure phase reversal in tube V_4A , the grid and plate potentials of tube V_5A should now be 180 degrees apart. This may be checked with the cathode-ray oscilloscope using the grid V_5 and plate V_5 jacks.

Since the adjustments shown in the tables for the grid and plate sampling circuits are approximate, final adjustments should be made to obtain the desired deflection in the cathode-ray oscilloscope. The deflection can be changed by either changing the value of capacity in the stacked condensers or changing the number of active turns of the associated coil.

Next increase the excitation by means of the output-coupling V_5 control until the required output, as indicated by the antenna-current meter in the antenna-coupling unit, is obtained. At this time, if the antenna is of the series excited type, the relation of transmission-line current, as read on meter M_5A , to actual antenna current may be determined, and the adjustment of the pickup circuit for remote indication of antenna current may be made to obtain the proper reading on this meter. This meter should be located at some convenient point for the operating personnel.

In the case of a shunt-excited or direct-connected antenna, meter M_5A will read "antenna" current. For the shunt-excited antenna, the antenna-current reading should be the same as that of the antenna meter in the antenna-coupling unit.

At the rated carrier output of the transmitter, check the phase adjustments and observe the plate currents of the final stage tubes. The plate currents of V_4A and V_5A and the total-plate current should be as indicated in Table XIIC. The plate current of tube V_5A may be increased or decreased by changing the setting of the inter-grid-coupling control. This requires a slight readjustment of the grid V_4 control to maintain the 90-degree phase relation. The plate efficiency of the final stage for the normal carrier output should be 60 per cent.

At this point, a final check should be made of the radio-frequency by-pass tuning. This should be followed by observing the grid phase relation and retuning of the grid circuits if necessary.

With the required carrier output, adjust condenser $C_{35}A$ until the feed-back current, as indicated by the test meter, when the test-meter switch is in the F.B. $\times 20$ position, is 7 ± 3 ma.

17. ADJUSTMENT OF FEED-BACK AND ASSOCIATED CIRCUITS.—After the entire transmitter has been tuned, adjustments of the feed-back circuit and associated circuits should be made. To measure the feedback, remove the feed-back rectifier tube V_7A and modulate the transmitter

with a single frequency of 400 cycles, noting the required input level for 100 per cent modulation. When the tube is replaced, the audio input level for 100 per cent modulation should be approximately +6 db (+14 VU). The difference of the two input levels is then the value of feedback. To obtain the proper value of stable feedback (20 to 22 db), adjust the setting of $R_{39}A$ until the input level is +8 db (+16 VU) for 100 per cent modulation and observe the wave form on a cathode-ray oscilloscope for different values of modulation. If a spurious oscillation appears, it will be necessary to adjust the values of one or more of the elements designated $C_{87}A$, $C_{88}A$, $C_{56}A$, $C_{52}A$, $R_{63}A$, and $R_{61}A$. These components are composed of parallel or variable elements and can be changed, but in general it will be found that the values connected at the factory will give satisfactory performance. The procedure of observing the wave form at different levels of modulation should be repeated for 50-cycle modulation. When the tests indicate no spurious oscillations, the feedback should be reduced 2 or 3 db by reducing the setting of $R_{39}A$.

Whenever major adjustments of the radio-frequency circuits of the transmitter are to be made, the feedback should be removed by changing the setting of $R_{39}A$ to zero or by removing V_7A .

18. AUDIO-MONITORING RECTIFIER.—The radio-frequency rectifier tube V_6A and its associated circuit furnish a source of audio monitoring output from the transmitter. The output transformer terminating resistance $R_{37}A$ should be removed when the output is 500 to 600 ohms impedance. The output level with single frequency 100 per cent modulation is approximately +10 db (+18 VU).

19. MODULATING THE TRANSMITTER AND FINAL ADJUSTMENTS OF RADIO-FREQUENCY CIRCUITS.—With the final stage adjusted to the proper operating condition at the unmodulated carrier output, it is necessary next to observe the operation with modulation applied.

For ideal distortionless operation with no carrier shift, the antenna current should rise 22.5 per cent at 100 per cent sinusoidal modulation (see Sec. 12.9). In transmitters not employing negative feedback, a failure of the antenna current to rise to this extent ordinarily indicates distortion in the modulated wave. With the distortion removed by feedback, the only result of such carrier shift is a slight decrease in transmitted signal; for example, if the antenna current rises only 19 per cent, the loss in transmitted signal with a distortionless wave is 0.25 db. The tendency for carrier shift to occur depends on local conditions, such as instantaneous line regulation, as well as on the adjustment of the transmitter.

This equipment is designed to permit 100 per cent modulation with no carrier shift, provided the line voltage does not change more than 2 per cent between the modulated and unmodulated condition.

The antenna-current increase for 100 per cent modulation is governed by the setting of the output-coupling V_3 control and the plate impedance of V_5A . The first adjustment for the required 22.5 per cent increase with 100 per cent single-frequency modulation should be made with the output-coupling V_3 control. The greatest increase will be obtained at the setting of optimum coupling, that is, at the position of the output-coupling V_3 control where the greatest value of carrier output is obtained. The R.F. output control must be adjusted in conjunction with the output-coupling V_3 control to obtain the required carrier output. If, at the setting of optimum coupling, the antenna current increase is too great, the coupling should be reduced and the setting of the R.F. output control readjusted for normal carrier output. With this procedure, a setting will be found that gives the required antenna current increase. If, however, the plate impedance of V_5A is too high and the desired increase is not obtained with the output-coupling V_3 control at the optimum setting, it will be necessary to reduce the number of active turns in $L_{15}A$. The turns in $L_{15}A$ should be increased by essentially the same amount that the turns in $L_{16}A$ are decreased. The phase relation of the plate circuits should be checked and the plate V_4 and plate V_5 controls adjusted when the number of active turns of those coils is changed. This change should be made one turn at a time and should not exceed a total of seven turns at 550 kilocycles and two or three turns at 2,750 kilocycles.

20. FINAL ADJUSTMENT OF SLIDERS ON $R_{76}A$.—The sliders on $R_{76}A$ should be adjusted to provide a smooth-acting control for the radio-frequency output over the entire range of the R.F. output control. The left slider should be permanently spaced $1\frac{1}{4}$ in. from the left terminal. The second slider from the left should be adjusted for zero carrier output when the R.F. output control is at zero. With this control set at 80, the right-hand slider on $R_{76}A$ should be adjusted for the normal carrier output. The final adjustment of all the sliders on $R_{76}A$, $R_{77}A$, and $R_{78}A$ should be checked as the adjusting of one somewhat affects the voltage of the other.

21. ADJUSTMENT OF FREQUENCY-MONITOR VOLTAGE TAP.—A slider adjustment is provided on output coil L_3A of the third radio-frequency stage to obtain the necessary voltage for frequency-monitoring purposes. Sufficient voltage should be obtained by placing this slider one turn on either side of the other slider on the coil. The tuning of the third stage should be checked after the slider has been connected to the coil.

22. ADJUSTMENT OF MODULATION-MONITORING CIRCUIT.—The radio-frequency supply for modulation-monitoring purposes is obtained from terminal 12. The control designated R.F. MONITOR provides a means for adjusting this supply to the required level for the proper performance of the modulation-monitoring equipment. Adjustments of the R.F.

monitor control slightly affect the tuning of the final stage output circuit, making it necessary to check the tuning of that circuit.

23. ADJUSTMENT OF THERMOSTAT TD_1A .—Thermostat TD_1A and buzzer BZ_1A are provided to give warning of excess temperature within the transmitter, which can be produced by failure of the motor blower or clogging of the air filters. The thermostat is adjustable over a range of 120 to 150°F. and is provided with a dial numbered from 1 to 5. This dial should be set at 5 for all installations.

24. OPERATION AT REDUCED POWER.—The equipment required for the instantaneous switching of power is optional and is only necessary for stations whose day- and night-time power ratings are different. This equipment consists fundamentally of a magnetic contactor $S_{102}A$, relay $S_{101}A$, and the HIGH-LOW power switch $D_{101}A$. Magnetic contactor $S_{102}A$ changes the bias and plate potentials, relay $S_{101}A$ switches the feed-back circuit, while switch $D_{101}A$ is used to control the operation of the contactor and the relay.

Transmitter adjustments should first be completed with the power switch in the HIGH position. Then with the switch in the LOW position, adjust the sliders of $R_{86}A$ that furnish bias voltage to V_4A and V_5A under the reduced power condition until the required carrier output is obtained at a plate efficiency of 60 per cent. The approximate bias voltages for V_4A and V_5A are shown in Table XIIB. When these adjustments are properly made, the correct value of carrier output will be obtained for both power conditions without changing the setting of the R.F. output control.

Operation of the power switch causes contactor S_1A to drop out, thereby removing plate and grid power before magnetic contactor $S_{102}A$ operates. The bias switch must therefore be operated to reapply the bias and plate power for the new power condition.

Condenser $C_{85}A$ and resistance $R_{39}A$ should now be adjusted to obtain the desired feedback at the two power conditions. With the power switch in the LOW position, adjust $C_{85}A$ until the desired feedback is obtained or until the audio input level for 100 per cent single-frequency modulation is +6 db (+14 VU). With this adjustment completed, place the power switch in the HIGH position and adjust $R_{39}A$ until the same audio input level is required for 100 per cent modulation.

25. TIME-DELAY AND RECYCLING CIRCUIT.—The tube filaments of this transmitter should be heated for not less than 30 sec. before applying the grid and plate power. Normally this delay is manual, but a time-delay and recycling circuit may be installed as an optional feature. In case of a power-supply interruption, the recycling feature provides a delay in the reapplication of grid and plate power proportional to the duration of the interruption. The reapplication of power is instantaneous for interruptions of less than one-half second. When the time-delay circuit is supplied, bias switch $D_{102}A$ is of the toggle type.

26. MAINTENANCE. *a. Motor Blower.*—The motor should be oiled in accordance with the manufacturer's recommendation.

b. Air Filters.—The filters should be removed and washed by running hot water through them once every 2 to 4 weeks. The elapsed time is dependent upon the amount of dust at the transmitter location. It is better practice to wash them often, for clean filters allow a greater circulation of air which therefore keeps the transmitter cooler.

c. Voltage Regulator T_1A .—The brush and commutator surface of this regulator should need very little attention. Should the brushes show signs of an irregular surface, a very fine grade of sandpaper should be placed under them and the brushes run up and down until they are smooth. If the commutator surface needs cleaning, the sandpaper should be placed below the brushes and held to the brushes while they are run up and down.

d. Relays and Magnetic Contactors.—The contacts of relays and magnetic contactors should be kept free of dust and any substance that might produce sticking. A fine grade of sandpaper should be used only when the contacts become pitted. Sticky or otherwise dirty contacts or relay mechanisms should be washed with a grease solvent such as gasoline or carbon tetrachloride.

TABLE XIIB.—VACUUM TUBES REQUIRED

Desig. No.	Code No.	Grid voltage	Screen voltage	Plate voltage	Filament voltage
V_{1A}	349A	20 ± 5	235 ± 10	235 ± 10	6.3 ± 0.2
V_{2A}	350A	22 ± 5	220 ± 10	490 ± 10	6.3 ± 0.2
V_{3A}	331A	60 ± 15$	.....	1,450 \pm 50$	10.0 ± 0.2
$V_{4.1A}, V_{4.2A}^1$					
$V_{5.1A}, V_{5.2A}$	357A	440 ± 10$	.....	3,500 \pm 50$	10.0 ± 0.2
$V_{4.1A}, V_{4.2A}^2$	357A	480 ± 20$	.....	2,500 \pm 100$	10.0 ± 0.2
$V_{4.1A}, V_{4.2A}^3$	357A	480 ± 20$	.....	1,800 \pm 50$	10.0 ± 0.2
$V_{5.1A}, V_{5.2A}^2$	357A	440 ± 20$	.....	2,500 \pm 100$	10.0 ± 0.2
$V_{5.1A}, V_{5.2A}^3$	357A	440 ± 20$	.....	1,800 \pm 50$	10.0 ± 0.2
V_6A, V_7A	351A	.....	.....	.....	6.3 ± 0.2
V_8A	349A	12 ± 2	190 ± 10	190 ± 10	6.3 ± 0.2
$V_{9.1A}, V_{9.2A}$					
$V_{9.3A}, V_{9.4A}$	350A	19 ± 2	245 ± 5	490 ± 10	6.3 ± 0.2
V_{10A}	301A	.....	.....	.....	5.0 ± 0.15
V_{11A}, V_{12A}	267B	.....	.....	.....	5.0 ± 0.15
V_{13A}, V_{14A}	249B	.....	.....	.....	2.5 ± 0.1

¹ For the 443A and 442A R.T.E. except $V_{4.1A}$ and $V_{5.1A}$ not used in the 442A equipment.

² For the 443A and 442A R.T.E. at one-half normal carrier power output. $V_{4.1A}$ and $V_{5.1A}$ not used in the 442A equipment.

³ For the 443A R.T.E. at 250 watts carrier output.

All screen and plate voltages are measured with respect to ground. The grid voltage tabulated for V_{1A} is with respect to the cathode of that tube. The remaining grid voltages are measured with respect to ground and are obtained by means of cathode resistors in all cases except the voltage for V_1A and V_4A which is obtained from a bias supply rectifier.

TABLE XIIC.—TYPICAL METER READINGS

Desig. No.	Title	Reading
M_1A	Power supply, volts	230 volts
M_2A	Amplifier plate, kilovolts	Function of power
M_3A	Total plate, amperes	Function of power
M_4A	Antenna or transmission line, amperes	Function of power and antenna or transmission line impedance
M_5A	Test meter switch Position	
	Mon. $\times 20$	7 ± 3 ma.
	F. B. $\times 20$	7 ± 3 ma.
	P. V8 $\times 100$	24 ± 4 ma.
	P. V9.1 $\times 200$	60 ± 5 ma.
	P. V9.2 $\times 200$	60 ± 5 ma.
	P. V9.3 $\times 200$	60 ± 5 ma.
	P. V9.4 $\times 200$	60 ± 5 ma.
	G. Osc. #1 $\div 2$	0-100 microamp.
	G. Osc. #2 $\div 2$	0-100 microamp.
	P. Osc. $\times 10$	2.5 ± 0.5 ma.
	P. V1 $\times 20$	10 ± 8 ma.
	G. V2 $\times 20$	0 to 1 ma.
	P. V2 $\times 100$	55 ± 10 ma.
	G. V3 $\times 20$	12 ± 6 ma.
	P. V3 $\times 200$	110 ± 20 ma.
	P. V5.1 $\times 200$	Function of power and modulation
	P. V5.2 $\times 200$	Function of power and modulation
	P. V5 $\times 500$	Function of power and modulation
	P. V4.1 $\times 500$	Function of power and modulation
	P. V4.2 $\times 500$	Function of power and modulation
	P. V4 $\times 1000$	Function of power and modulation

12.6. Relay Operation.—To illustrate the practical operation of the power-control and protection circuits of an entire transmitter, we have chosen to explain how these devices operate on the Western Electric 12A transmitter and 71A power amplifier. The complete installation is shown in the schematic diagram in Fig. 12-11.

Assuming that the power switch Sw_1 is closed, the following sequences occur:

1. The switch Sw_1 connects a three-phase 220-volt 60-cycle source to the various circuits of the 12A and 71A units and is closed when the transmitter is in operation. These circuits, with the exception of the transformer T_1 , will, however, not be energized by the closing of this switch. The transformer T_1 must be constantly energized in order to operate the temperature-control chamber of the crystal box to maintain a constant-operating frequency. The primary winding is, therefore, permanently connected across the alternating-current line. If this switch is left open for a considerable time the temperature in the crystal chamber will be altered, and a frequency deviation of several hundred cycles may result. This transformer supplies the fila-

ment, plate, and bias voltages for the argon regulator tube V_1 . The operation of this circuit will be explained later.

2. The next switch to be closed is Sw_2 . This supplies an alternating-current voltage across an autotransformer T_2 . A tapped portion of this transformer connects to a rotary switch for the purpose of selecting the proper alternating-current voltage to be delivered to the operating circuits. This provides the proper flexibility necessary to maintain the desired voltage to the load circuits to compensate for line-voltage changes. This voltage must be maintained at 220 volts as indicated by the alternating-current line voltmeter M_1 . Any variation in the supply-line voltage may then be regulated by the rotary switch to the required value.

The autotransformer voltage excites the primary windings of all the filament-lighting transformers in the 12A unit, T_3 , T_4 , and T_5 , and the master-control relay A in the 71A amplifier unit, which closes and excites the primary windings of the filament transformers T_6 and T_7 for the power amplifier and rectifier tubes, respectively.

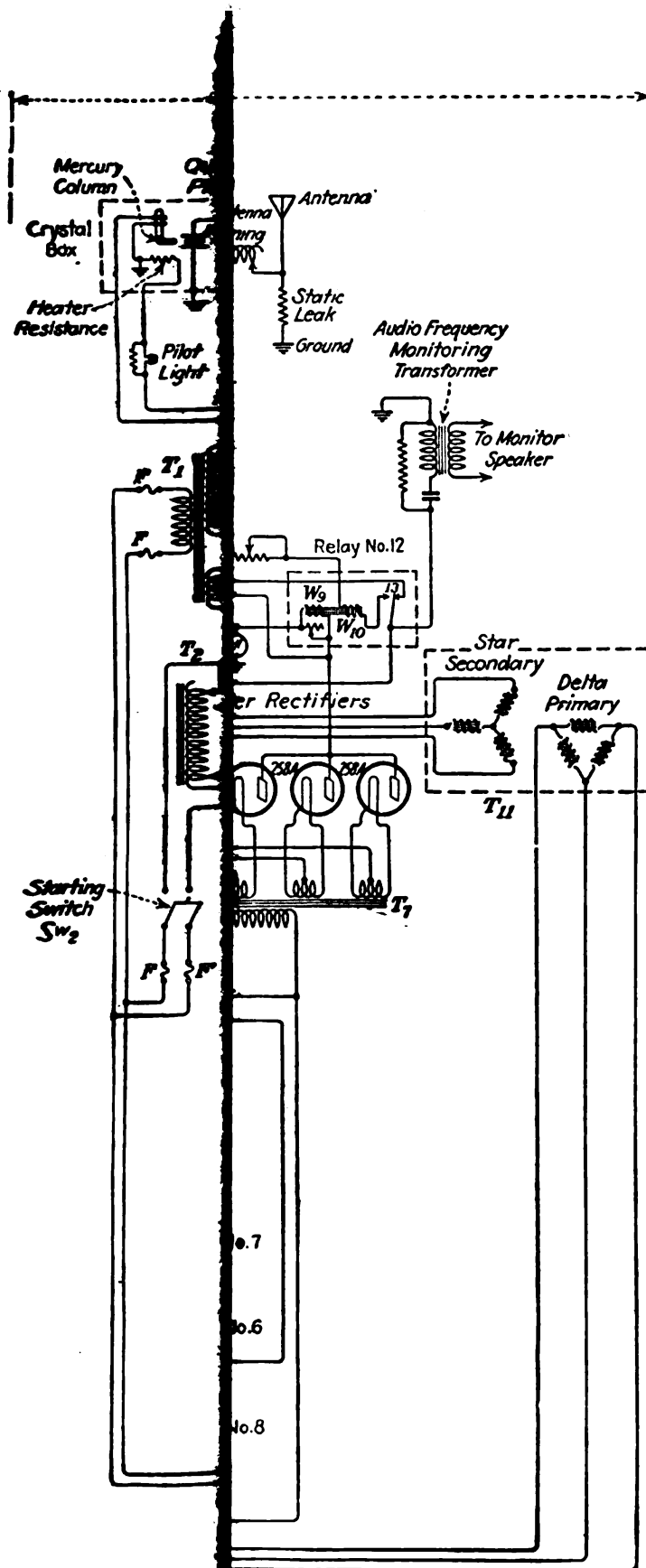
3. Connected across the secondary winding of the filament transformer T_4 is a resistance unit which becomes heated when the winding is energized. This unit (and its associated contacts) is known as a *thermal* or *heater-element time-delay relay*, relay 1. This resistance is located very close to an alloy strip (thermal element) which, when heated, begins to expand owing to the effect of heat on the metal. As this metal strip expands sufficiently, it finally makes contact with the terminal 1 on the unit and energizes another relay coil winding W_1 of relay 2. The magnetized winding of this coil attracts two metal contact strips which, when closed, open up the connection to the heater unit of relay 1 and close the circuit leading to the primary winding of the transformer T_6 . This transformer supplies the plate voltage to the oscillator and buffer-amplifier stages only and also supplies the negative bias to the grids of the first amplifier and modulating radio-frequency amplifier stages. It is important to note, however, that relay 2 cannot be actuated unless relay 3 is also closed. The latter can be operated only when all door switches are closed by tightly locking all compartment doors.

Now, since the heating resistance unit of relay 1 is open-circuited, the heating effect upon the metal strip will be decreased and consequently will cause the strip to return back to its normal position. This closes the back contacts 2 and completes the circuit through the relay 4, winding W_2 . This closes the contact 3 on this relay and excites the primary winding of the plate-voltage transformer T_6 . It is assumed, of course, that the plate-supply switch Sw_3 and the door-switch relay 3 have been previously closed.

4. The overload relay 5 in the 12-A unit of the transmitter consists of two coils, namely, the overload-coil winding W_4 and the operating winding W_5 . The overload coil is connected in series with the center-tapped filament return lead to ground which completes the plate-current circuit for the modulated radio-frequency amplifier tubes. If an abnormal flow of plate current should result in these tubes due to excessive modulation peaks or line-voltage surges, the winding W_4 of relay 5 will be energized sufficiently to draw over the contactors and close the circuits 4 and 5. This action will short-circuit the winding of relay 4, thereby demagnetizing it and releasing the contacts 3 on the relay 4. Thus the primary winding of the plate-supply transformer T_6 will be opened and the high voltage to the modulated amplifier tubes will be disconnected.

5. A small-overload reset push button (not shown) is provided to open the winding W_4 so that the short circuit will be removed from the winding W_2 on relay 4 and thereby reestablish the plate voltage to the modulated amplifier tubes.

6. The relays in the 71A unit operate in a similar manner to those in the 12A unit with the exception that they are designed to carry relatively larger values of currents.



(Facing page 622.)



When the master-control relay *A* is closed, the primary winding of the filament transformers T_6 and T_7 are excited as stated before. At the same time, however, another thermal time-delay relay 6 is heated, since it is connected across the primary windings of the two filament transformers T_6 and T_7 . This results in the expansion of the thermal element and the closing of contacts 6 and 7; and this allows current to flow through the winding W_6 which energizes relay 7. When this relay is energized, the contact 7 is opened and the heater winding of relay 6 is broken, thus allowing the thermal element to contract and reestablish connections 5 and 6 on relay 6. At the same time, however, the contact 8 is closed which allows a current to flow through the winding W_7 . This magnetizes relay 8 and closes the contacts 9 and 10. The closing of these contacts allows an alternating current to flow through the primary winding of the transformer T_{10} and establish a voltage between the two plates of the associated mercury-vapor rectifier tubes. This results in a current flow through the resistance R_1 which develops a voltage drop across it. This drop is used to supply the bias of -275 volts to the grids of the two power-amplifier tubes V_7 and V_8 . This is, of course, provided that the relay 9 is also closed by having all door switches locked. Otherwise contact 11 will be open and no current will pass through T_{10} .

7. As soon as the grid-bias voltage is developed across the resistance R_1 , a current will pass through the grid-bias relay 10 because it is connected directly across the resistor through contacts 13. This actuates the relay winding W_8 by magnetizing the iron core and closing the contacts 14 and 15. In series with these contacts is a large solenoid contactor, relay 11, which becomes energized and draws over three contactors to close the three-phase alternating-current supply to the high-voltage transformer T_{11} . This action supplies the alternating-current high voltage to the plates of the main power-amplifier mercury-vapor rectifier tubes, where it is then rectified to the desired direct-current potential of 3,000 volts for the plate supply.

8. All circuits should now be excited and the proper plate, bias, and filament voltages should be applied. These voltages may now be properly checked by the filament voltmeter M_7 and the direct-current voltmeters M_8 and M_9 . All plate and radio-frequency currents may also then be checked by the various plate milliammeters MA , and by the radio-frequency ammeters RFA , in the respective circuits.

9. In the Western Electric installation only one milliammeter is used to obtain the plate- and grid-current readings for several of the low-power stages in the 100-watt unit. This is accomplished by a number of resistance shunts and a rotary-selector switch which transfers the meter into the desired circuit. In Fig. 12-11 this switch and the associated shunts are omitted, but individual meters are inserted in their proper places to simplify circuit analysis.

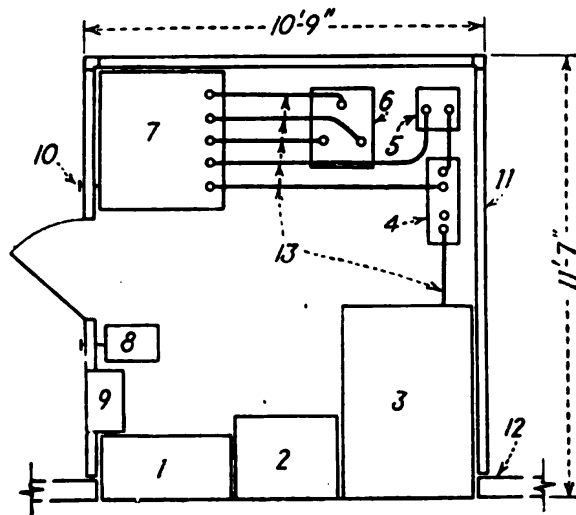
10. All plate- and power-supply circuits are suitably protected by fuses and overload circuit breakers as illustrated in the diagram. Two overload relays 5 and 12 are provided in the 100-watt and power-amplifier units to enable the operator quickly to reestablish transmitter operation in the event of a circuit breaker "tripping" owing to excessive modulation peaks, line-voltage surges, or temporary condenser flashovers due to dust accumulation.

11. The overload-coil winding W_9 of relay 12 is connected in series with the negative terminal of the 3,000-volt rectifier and ground. If an excessive value of current flows through this coil, the core is magnetized sufficiently to pull the relay arm over and break the contacts 13. This opens the winding W_8 on relay 10 and releases the contact arm of the relay, which breaks contacts 14 and 15 and opens relay 11. This disconnects the three-phase supply to the power transformers and cuts off the high-voltage supply to the power-amplifier tubes. The winding W_{10} on the overload relay 12 serves to hold the arm in this position until it is desired to reestablish the plate voltage.

12. A push-button reset switch (not shown) is connected in series with winding W_{10} to break this circuit when it is desired to release the arm back to its normal position, thereby reestablishing contacts 13, 14, and 15 and again energizing winding W_8 of relay 10.

12.7. Western Electric 5-kw. Broadcast Transmitter: a. General Description.—A schematic circuit arrangement of the Western Electric 405B-2, 5-kw. radio-transmitting equipment is shown in Fig. 12-12. This transmitter incorporates all the advantage of the older water-cooled 405A-1 transmitter, with the essential engineering difference that the power-amplifier tubes of the 405B-2 transmitter are air cooled.

This transmitter also includes the Doherty high-efficiency amplifier and stabilized feed-back features. Additional features are an automatic



- | | |
|------------------------------|---|
| 1. Control unit | 8. Induction regulator |
| 2. Oscillator amplifier unit | 9. Power distribution panel |
| 3. Power amplifier unit | 10. Grounding switch |
| 4. High-voltage condensers | 11. Sectionalized metal and glass partition |
| 5. High-voltage choke coil | 12. Building partition |
| 6. High-voltage transformer | 13. High-voltage bus |
| 7. High-voltage rectifier | |

FIG. 12-13.—Typical apparatus layout for W.E. 405B-2 transmitter.

circuit breaker and reclosing contactor in the power circuit to the rectifier, an automatic voltage regulator, use of circuit breakers for overload protection, ample meters to provide visual indications of circuit conditions throughout the transmitter, provision of cathode-ray oscillograph connections in all important circuits, and key-operated tuning controls. The transmitter is entirely alternating-current operated. A typical apparatus layout for the 405B-2 transmitting equipment is shown in Fig. 12-13.

b. Design Features.—The frequency range of this transmitter is 550 to 1,600 kilocycles; that is, it may be tuned to any frequency within this range. The carrier-power output possible is normally 5,000 watts. The output power may be automatically reduced to 2,500 or 1,000 watts as adjusted by push-button control. The power supply is 210 to 250

volts, 60-cycle three-phase power. This transmitter can also be supplied to operate from a 50-cycle source of supply with the voltages specified. The power consumption has been measured as follows: 15.3 kw. for carrier only; 15.75 kw. for average program; and 19.5 kilowatts for single frequency, all modulation 100 per cent on peaks.

The transmitter consists of three units arranged to form one side of an enclosure. The power apparatus, consisting of a distribution cabinet, regulator, transformers, and filters, is installed in an enclosure behind these units. The high-voltage rectifier may be installed immediately behind the control unit or elsewhere in the enclosure as shown in Fig. 12-13.

For the standard arrangement, a sectionalized metal and glass partition may be used for the protection of the personnel. This enclosure, which contains the high-voltage power apparatus behind the transmitter units, can be provided for standard layouts. When visibility such as is afforded by this partition is not essential, fireproof wall construction may be utilized.

The vacuum tubes required for this transmitter are as follows:

Oscillator Amplifier:

- 1 type 247A tube for oscillator.
- 2 type 837 tubes for first and second radio-frequency amplifiers.
- 2 type 241B tubes for modulating radio-frequency amplifier.
- 1 type 310A for first audio-frequency amplifier.
- 2 type 837 tubes for second audio-frequency amplifier.
- 4 type 249B tubes for plate- and screen-supply rectifiers.
- 1 type 274A tube for grid-bias rectifier.
- 2 type 84 tubes for feed-back and monitoring rectifiers.

An additional socket is provided in this unit to keep a spare 249B tube ready for instant service.

Power Amplifier:

- 2 type 220CA tubes for radio-frequency power amplifier.
- 1 type 274A tube for protective-circuit rectifier.

Control Unit:

- 1 type 313A tube for use in 246A relay.

High-voltage Rectifier:

- 4 type 249B tubes for grid-bias rectifiers.
- 6 type 315A tubes for plate-supply rectifier.

An additional socket is provided in this unit to keep a spare type 315A tube ready for instant service.

Frequency control is achieved through a 702A oscillator containing a low-temperature-coefficient quartz plate. Provision is made for a spare oscillator with a selector switch on the front panel which permits the use of either oscillator.

The cooling system consists of a motor-driven blower which forces filtered air through the cooling fins of the type 220CA tubes. This filtered air escapes at the top of the unit. Two speeds of the blower are

provided, the low speed for normal use, and the high speed for use when there are very high ambient temperatures. The air-cooling system here used eliminates the pump troubles, water leakage, and plumbing which are encountered when a water-cooling system is used, which is a considerable improvement in design.

This equipment is designed to operate at locations where high ambient temperatures are encountered. Since there is no water to freeze, it may be used in locations in which the heating is not adequate to maintain temperatures above freezing during periods when the transmitter is off the air.

Toggle switches are provided to control the power to the transmitter. Delay and sequence relays prevent the bias and plate voltages from being applied until the tube filaments are properly heated. All controls may be multiplied to the control desk. Controls are provided on the transmitter for separately adjusting the filament voltage applied to either power-amplifier tube, and high-reactance filament transformers are used to prevent injurious filament starting currents.

A recloser associated with the closing circuit automatically recloses the high-voltage plate breaker once in the event it is tripped by an overload. After an operation, the recloser resets itself whenever the breaker remains closed any preset time between 9 and 90 sec. Although the breaker recloses automatically but once in any interval less than the predetermined time, a push button enables the operator to further reclose as many times as he wishes.

An automatic voltage regulator is furnished with the equipment for controlling the voltage of the entire power input to the transmitter. Constant voltage is maintained which insures long life for the tubes and the equipment and relieves the operating personnel from the duty of adjusting for changes in line voltage.

Three single-phase transformers are mounted in a case filled with non-inflammable oil, thus permitting indoor installation without the use of a fireproof vault. Each transformer is brought out to individual terminals, and an open-delta connection can be obtained (normal connection is closed-delta) of sufficient capacity to permit continuous operation, thus providing the equivalent of a spare transformer.

The filter retard is also housed in a case filled with non-inflammable oil. This feature allows indoor installation.

Two filter condensers are mounted in a small steel angle frame structure together with a condenser charging resistor and a voltmeter multiplier. Only a slight amount of hum would be introduced by the temporary emergency disconnection of one of these condensers.

Completely assembled and wired at the factory, the power-distribution cabinet may be installed with the minimum of time and effort. The incoming power is distributed to the parts of the transmitter requiring power, through "no-fuse" circuit breakers and electrically operated switches.

As associated equipment the Western Electric 705B speech-input bay is recommended for installation at the transmitter location. The Western Electric 23C speech-input equipment is recommended for installation at the studio.

Complete facilities are provided for connection of the station's frequency and modulation monitors. A program monitor is provided as part of the transmitter. The output of this monitor may be connected to any loud-speaker system.

c. Electrical Characteristics.—Because a Doherty amplifier is used, the efficiency of the power-amplifier stage is normally 60 per cent instead of the usual 30 per cent obtained without this circuit. With this circuit, there is a reduction in plate dissipation which makes air cooling possible.

Measurements show this transmitter to have a frequency response which is flat within plus or minus 1 db from 30 to 10,000 cycles. The speech-input level is +12 VU (16 mw.) for program signal and +18 VU for a single frequency with 100 per cent modulation. The program level range is 60 db.

This transmitter is equipped with stabilized feedback. This feature controls harmonic distortion and noise and provides high-fidelity performance in accordance with the accepted standards in this respect. This stabilized feedback is automatic in operation and independent of transmitter operating adjustment. In regard to distortion, a typical value of r.m.s. audio-frequency harmonic distortion in the frequency range of 50 to 5,000 cycles per second does not exceed 4 per cent at 85 per cent modulation or 5 per cent at 100 per cent modulation.

The amplifiers are designed to carry over 100 per cent modulation peaks without program interruption or damaging effect to circuit components or tubes. This ability is a direct result of the continued development and research in low-level modulation systems and the associated stabilized feed-back circuits.

The r.m.s. noise level of this equipment is 60 db unweighted. No radio-frequency harmonic greater than 0.03 per cent (voltage) of the fundamental is radiated. This corresponds to better than 70 db below the output at the fundamental frequency.

Low-level grid-bias modulation is used. The carrier frequency is maintained well within 10 cycles of the assigned frequency by means of a crystal-controlled oscillator in a heat-controlled chamber.

Antenna coupling units are available to couple this transmitter into a single shunt-fed or series-fed antenna or in conjunction with antenna control equipment into a multiple-unit array.

Maximum protection to the operating personnel is provided by a dead-front type of construction and by safety switches which operate and remove all high voltages before any dangerous circuits can be touched. The transmitter fully complies with all the FCC requirements of good engineering practice.

12.8. The Frequency Monitor.—Figure 12-14 illustrates the wiring diagram of the Western Electric type 1-A frequency-monitoring unit which employs a calibrated crystal and temperature-control chamber identical with that explained in Chap. 4 on Transmitting Circuit Principles. In addition to the oscillator, an audible and visual indicator is provided to show the frequency variation of the carrier wave, two screen-grid radio-frequency amplifiers, one detector, one argon regulator, and one mercury-vapor full-wave power-rectifier tube. The entire unit is operated from an alternating-current 110-volt or 220-volt 60-cycle power-supply system.

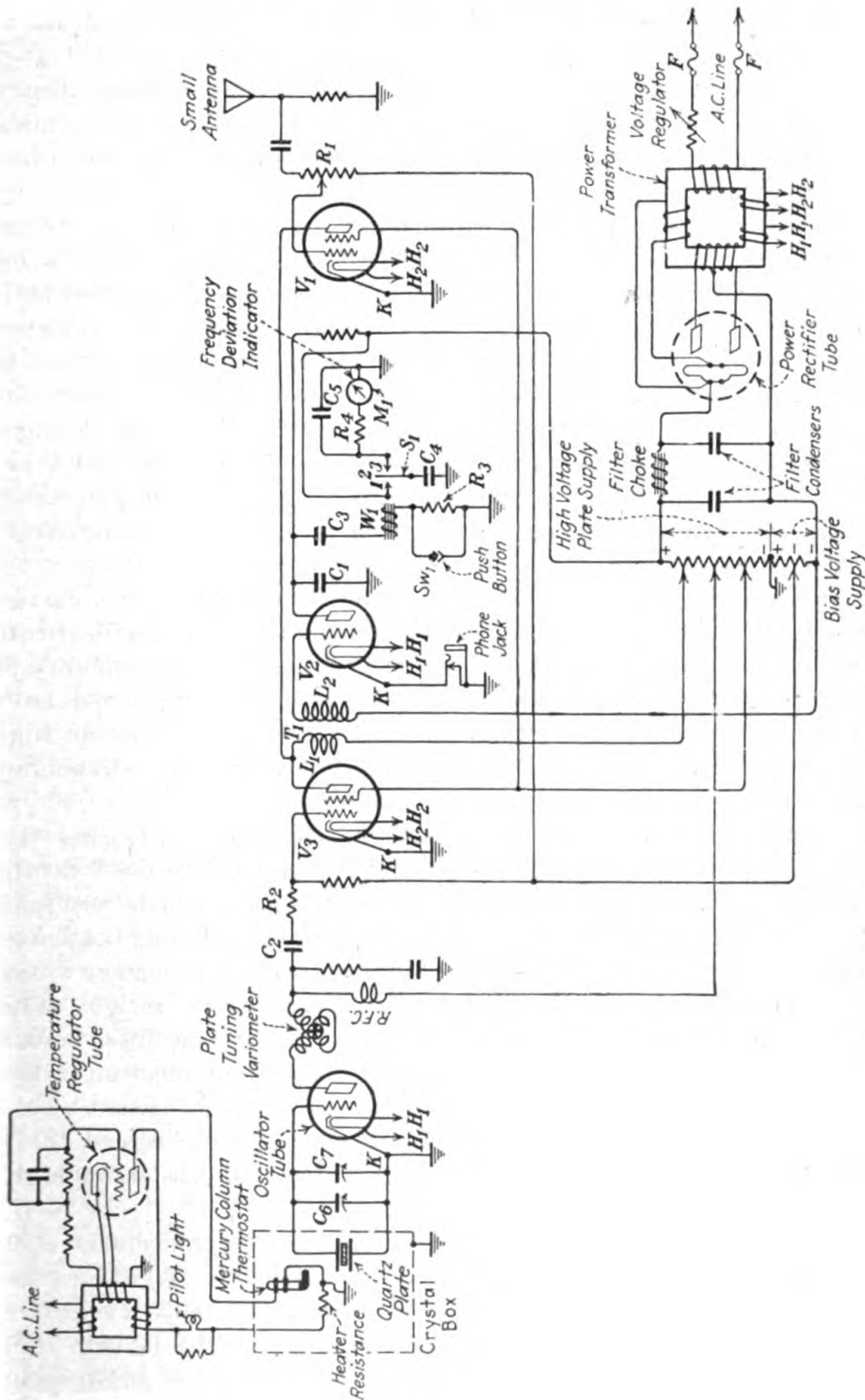


FIG. 12-14.—Western Electric type 1-A frequency monitoring unit.

The monitor unit is capable of indicating a frequency deviation of ± 75 cycles of the carrier wave from its assigned frequency.

A small antenna is generally used to pick up the radio-frequency voltages from the transmitter, although it is also possible to determine variations by connecting the monitor to a receiver tuned to the transmitter frequency.

The theoretical operation of the monitor unit is as follows. When the radio-frequency voltages from the carrier frequency are picked up by the small antenna, they are applied across the grid-cathode terminals of the screen-grid tube V_1 , the intensity of the voltage being regulated by the potentiometer R_1 . These voltage changes then produce plate variations at a radio frequency in the tube which pass through the primary winding of the radio-frequency transformer T_1 . The voltages are then applied across the grid and cathode of tube V_2 by induction from L_1 to L_2 . This tube is so biased negatively that the radio-frequency voltages on the grid produce asymmetrical pulses in the plate circuit (detection).

Now let us assume that these variations are the result of a carrier frequency of 500,000 cycles. Although this frequency is rectified into unilateral pulses, the sequence of the positive peaks is of such rapidity as to be beyond audibility or visibility. Hence, these high-frequency pulses cannot pass through the relay winding W_1 , owing to its high reactance to high frequencies, but will pass through the radio-frequency plate by-pass condenser C_1 .

Assuming that the crystal oscillator is in operation at the same frequency, 500,000 cycles, the high-frequency voltage developed in the output of the oscillator will be applied across the grid-cathode terminals of the radio-frequency amplifier tube V_3 through the coupling condenser C_2 and the feed resistance R_2 . This will cause another frequency variation of 500,000 cycles to be present in the plate circuit of V_2 . This frequency too will induce an e.m.f. across the detector tube V_2 as before. Thus two sustained frequencies, namely, the one from the transmitter and the one from the oscillator, are present in the plate circuit of the tube V_2 . Hence, since both of these frequencies are assumed to be identical, their resultant rectified plate variations will pass through the by-pass condenser C_1 .

Let it now be assumed that the frequency of the transmitter is 25 cycles higher than that of the oscillator standard, or 500,025 cycles. Thus two radio-frequency voltages of 500,000 and 500,025 cycles will be developed across the grid and cathode of detector tube V_2 with their resultant variations flowing in the plate circuit through C_1 . However, since both of these frequencies are flowing through C_1 , they beat against one another and develop across the condenser periodic additions and cancellations of voltage to the value of the difference between the two

radio frequencies. The resultant difference between the two frequencies is in the low-frequency range, that is, 25 cycles. Hence, the low-frequency rectified pulses will readily pass through the reactive circuit C_3 , W_1 , and R_3 and energize the sensitive relay S_1 . (R_3 must be short-circuited by closing frequency-test switch Sw_1 to pass sufficient current to energize W_1 .) This action will attract the vibrating arm and close the contacts 1 and 2 and charge the condenser C_4 . At the instant the low-frequency pulse through W_1 ceases, the arm returns and closes contacts 2 and 3, allowing the condenser C_4 to discharge through the frequency indicator M_1 . Hence the periodic low-frequency variations of the rectified pulses through W_1 will allow the condenser C_4 to discharge at a definite rate and in one direction only through the direct-current meter M_1 . The condenser C_3 and the resistance R_4 control the discharge rate of the charging condenser C_4 to produce the proper damping effect on the moving element of the meter M_1 .

Now, if the frequency of the carrier wave is 499,975 cycles, or 25 cycles below the frequency-monitor standard of 500,000 cycles, the meter M_1 will still indicate the rectified pulses of 25 cycles. If, therefore, it is desired to ascertain if the frequency variation of the transmitter is -25 or $+25$ cycles the frequency of the monitor crystal must be slightly altered. This is done by inserting an extremely small capacity C_6 across the crystal. This condenser is operated by the same push button which closes the test switch Sw_1 . When the push button is gently pressed, the small capacity C_6 is varied toward minimum capacity by separating two small circular metal plates. When the push button is released, the capacity of C_6 increases very slightly as the plates move closer together.

Therefore, if the frequency-deviation indicator switch Sw_1 is closed and the frequency indicator M_1 reads 25 cycles, the push button is very slightly depressed and released, and the deflection of the indicator is again noted. If it tends to move slightly upward, it is an indication that the transmitter frequency is 25 cycles above that of the monitor standard, or $+25$ cycles. The reason for this action may be clearly seen if we recall that the crystal represents the equivalent of a tuned circuit in which the frequency is dependent upon the constants L and C . For example, if the value of C across an inductance is increased, the frequency period of the circuit will decrease. Hence, the small capacity C_6 across the crystal very slightly alters the monitor frequency and enables the operator to determine the direction of the frequency shift.

A small trimming condenser C_7 is connected across the quartz crystal. This condenser is permanently adjusted to half-capacity at the time of frequency calibration so as to provide flexibility, if it is found necessary to increase or decrease very slightly the oscillator frequency.

If desired, the monitor frequency may be checked periodically to insure that its indication gives a true reading of the transmitter frequency

at all times. Checking service may be had for a fee from several sources, among which is the RCA Communications at Riverhead, N.Y., or at San Francisco, Calif.

If an immediate check on the exact transmitter frequency is made by telephone, the crystal monitor may be immediately adjusted against the transmitter frequency owing to the fact that the transmitter is effectively standardized at that moment. The condenser C_7 on the monitor is adjusted until the monitor-frequency indicator reads exactly the same as that reported by the standard measurements. After this has been done, the monitor is calibrated with the standard and the transmitter may then be adjusted to minimum frequency variation, within ± 10 cycles as now indicated by the crystal monitor.

12.9. Modulation Measurements.—When the entire transmitter has been properly adjusted to the desired carrier-frequency stability and power requirements, a careful check of the modulation percentage must be made.

There are several practical methods of determining approximately if the transmitter here described is modulating over 85 per cent and not more than 100 per cent.

The simplest method and a fairly accurate one is that in which a single-tone frequency such as is supplied by the 60-cycle power line is fed into the radio-frequency stage to be modulated. Assuming that before modulation the output mesh current in the amplifier circuit is 1 amp. (this would be the exact amount of current necessary to indicate that 100 ohms are present in this circuit to dissipate the proper amount of power, namely, I^2R or 100 watts, and to excite the grids of the power-amplifier tubes) then, if the 60-cycle single tone is supplied directly to these tubes through the medium of the grid-modulation transformer T_{14} , and if the mesh current in the plate circuit, as indicated by the meter M_2 , reads 1.225 times (22.5 per cent rise) the normal amount of 1 amp., it is a fair indication that the carrier frequency is modulated 100 per cent. Hence, if, when the single tone is applied, the mesh or tank current rises to 1.225 amp., the transmitter is most certainly modulated at or very near to 100 per cent. Perhaps an even better check when using this method is to use the radio-frequency ammeter M_2 in the plate circuit of the power-amplifier tubes. For example, if this meter should read 3.2 amp. during the period in which the carrier frequency is unmodulated, then, if a 60-cycle single tone is supplied (by increasing the gain of the potentiometer control in the speech-input circuit) until the meter rises to a value 22.5 per cent higher than 3.2, or 3.9, amp., the carrier is modulated at approximately 100 per cent.

It is apparent that this method would be practically useless if anything other than a pure single tone were used owing to the difficulty of the meter to follow the peaks during complex modulation.

Various types of indicators called *peak voltmeters* or *modulation meters* have been designed to determine accurately the percentage of modulation by this method. Some of these instruments enable a constant check on the modulated frequency, even during the complex modulation while the program is in operation. This is accomplished by a time-lag circuit of capacity and resistance in conjunction with the indicating meter so that, when the needle follows a peak, it will momentarily stay in its deflected position and thereby permit a fair check on the modulation percentage during peaks.

Figure 12-15 illustrates the wiring diagram of a vacuum-tube peak voltmeter for indicating the percentage of modulation.

The radio-frequency output of the final stage of the transmitter is magnetically coupled to the input circuit of the voltmeter so that, when L_1 and C_1 are adjusted to the carrier frequency, a potential will be developed across the parallel mesh. This e.m.f. will be applied across the plate-cathode terminals of the rectifier tube through the medium of the direct-current-blocking, radio-frequency, by-pass condenser C_2 . The steady direct current flowing in the plate circuit through L_2 and R establishes a steady potential across them. If the radio-frequency voltage is unmodulated, no

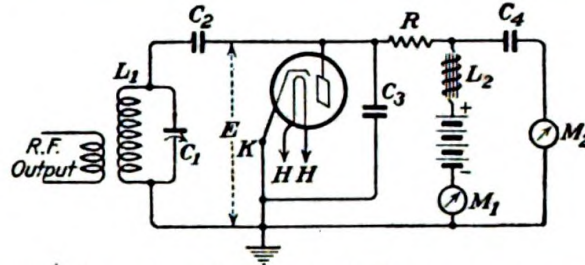


FIG. 12-15.—Vacuum-tube peak voltmeter for indicating percentage of modulation.

voltage variations will be developed across the resistance R owing to its high resistance and associated impedance L_2 . Hence, these radio-frequency variations will pass through the relatively low-reactance path of C_3 .

If, however, the radio-frequency carrier is modulated, the current through the resistance R will be varied in direct proportion to the audible rate at which the carrier is varied. Since this results in series of low-frequency pulses across C_4 and the meter M_2 , the condenser C_4 will discharge these pulses at an audio-frequency rate through the meter. Thus, if a single tone is used to modulate the carrier frequency, a direct scale reading of the effective modulation may be obtained by taking the ratio of the

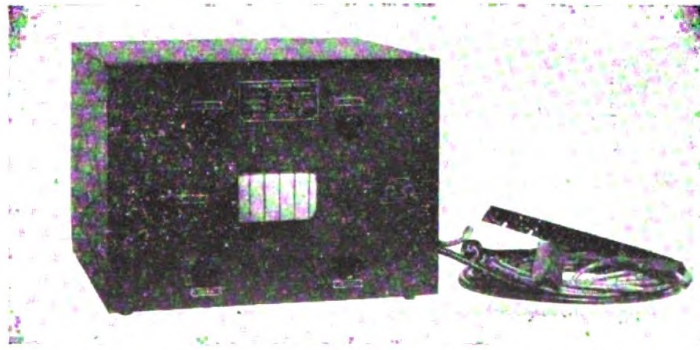


FIG. 12-16.—RCA Victor cathode-ray modulation indicator. (Courtesy of RCA Manufacturing Company, Inc.)

current through the direct-current meter M_1 to that of the alternating-current meter M_2 and multiplying it by the product of $\sqrt{2} \times 100$, thus,

$$\text{Modulation} = \left(\sqrt{2} \times \frac{I_2}{I_1} \times 100 \right) \text{ per cent} \quad (2)$$

The most accurate method, however, for determining the modulation percentage of a radio transmitter is by the use of the cathode-ray oscillograph. With this device an absolutely accurate indication of modulation percentage may be obtained at all modulated frequencies since the cathode ray operates at radio-frequencies and is not restricted to the sluggish audio frequencies. In other words, the necessity of rectification and its resultant damping losses are entirely obliterated because the indication is produced by the radio-frequency carrier frequency itself.

Figure 12-16 illustrates the RCA cathode-ray modulation indicator type 49-A which utilizes an RCA-904 cathode-ray tube. In this indicator a sweep circuit is employed using electromagnetic deflection as shown in Fig. 12-17. The modulation percentage indication is normally obtained by the operation of the vertical sweep connected to a 115-volt 60-cycle power supply, but it may be connected to some other source, if desired.

The radio-frequency carrier is picked up by a tuned circuit designed to cover the entire broadcast and police bands through the medium of a tapped coil. Three voltage-regulator circuits and a sweep-circuit potentiometer are provided for the necessary adjustments. When

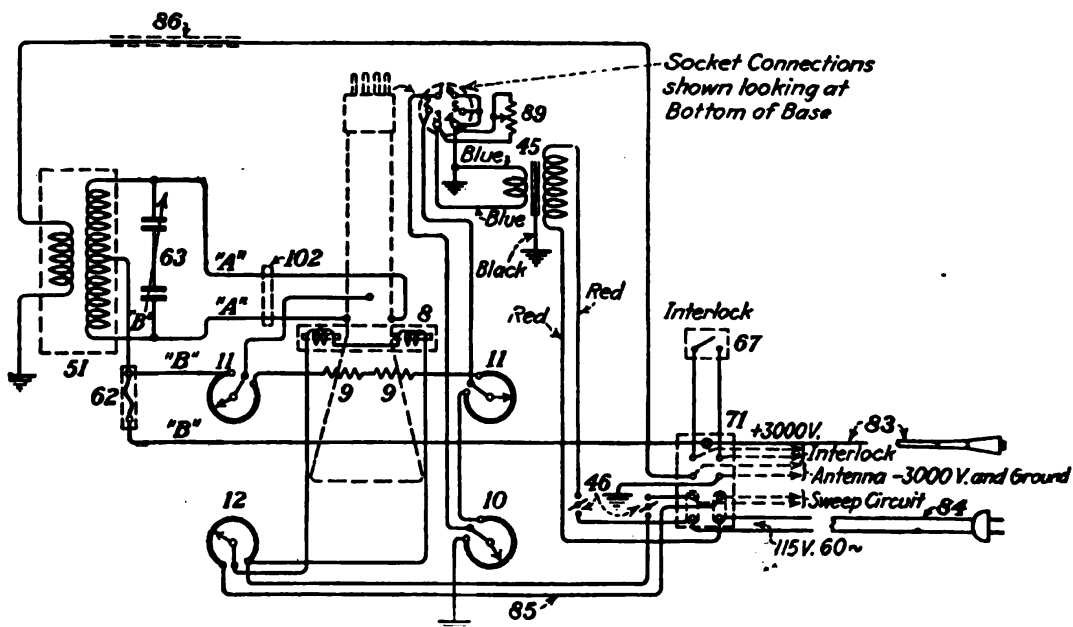


FIG. 12-17.—Sweep circuit of RCA Victor cathode-ray modulation indicator (type 49-A).
(Courtesy of RCA Manufacturing Company, Inc.)

these controls have been carefully regulated to the carrier frequency, a continuous wave form will appear on a fluorescent screen as shown in the illustration. This panel has three red lines and two black lines which serve to indicate the modulation percentage on both the positive and negative peaks of the cycle.

The unmodulated carrier frequency is adjusted so that it extends on both halves of the cycle to the black lines as illustrated in Fig. 12-18(a). Now let us assume that a single-tone frequency of 60 cycles is applied through the speech-input equipment with the proper output level to modulate the carrier. If the carrier frequency is varied in amplitude so that the peaks extend to the outer red lines, the carrier is said to be positively modulated at 100 per cent. If, at the same time, the decreased peaks or troughs extend to the center red line, then 100 per cent negative modulation is obtained. In other words, if the transmitter carrier frequency is completely modulated at 100 per cent, both the positive and

negative variations must extend to the outer and center red lines, respectively. This condition is illustrated in (b).

If, on the other hand, the carrier frequency is modulated only 50 per cent, the positive and negative peaks will extend only to half the value between the black and red lines as indicated in drawing (c). If the modulation is in excess of 100 per cent, the positive peaks will extend beyond the outer red lines and the negative peaks will be entirely ineffec-

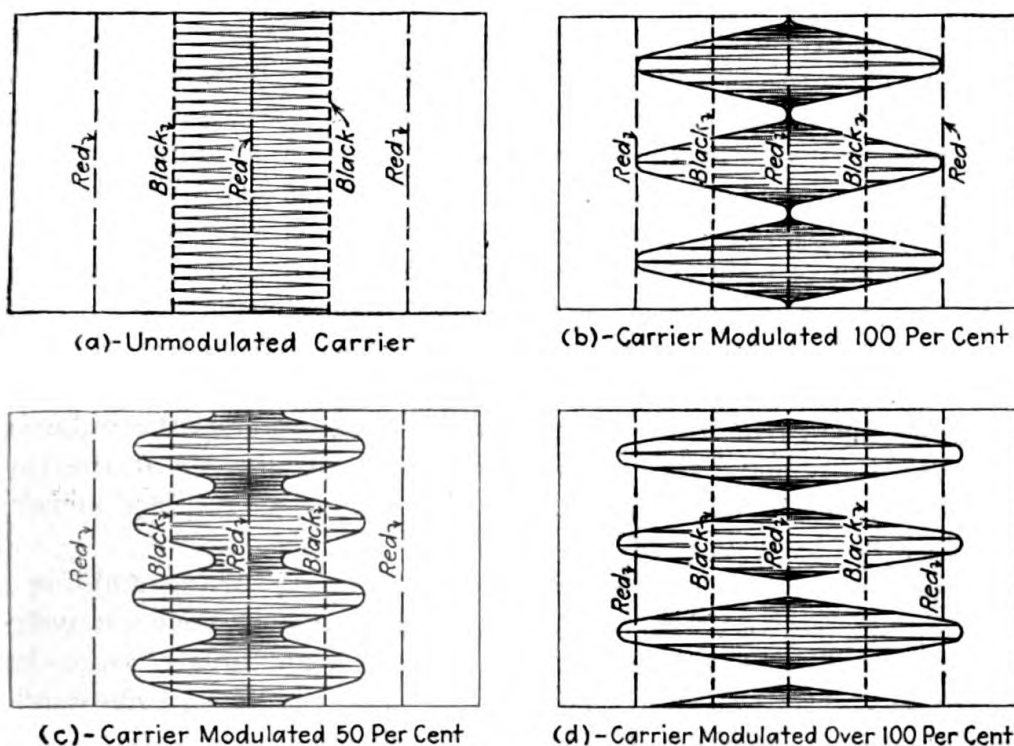


FIG. 12-18.—How carrier wave and modulation appears on fluorescent screen of RCA Victor cathode-ray modulation indicator. (Courtesy of RCA Manufacturing Company, Inc.)

tive as illustrated in drawing (d). This last condition effectively increases the damping of the modulated wave and introduces serious distortion.

Precautions: If the beam is allowed to play continuously on one spot of the fluorescent screen, the active coating may be permanently damaged. The position of the radio-frequency coupling coil (item 51, Fig. 12-17) should not be adjusted without removing the high voltage as it operates at a potential of 3,000 volts direct current.

II. BROADCAST ANTENNAS

12.10. Broadcast-transmitting Antennas.—In Sec. 7.2 and 7.4 on propagation of broadcast frequencies under Sky and Ground Waves, it was shown that the local area within the range of the ground wave is the important factor in calculating the service area of broadcast stations, and less attention is given to Heaviside-layer reflections because of their instability. Therefore, broadcast-antenna design is directed toward increasing the percentage of power radiated in the ground wave.

It is generally desired to have a non-directional field in the horizontal plane, and for this reason quarter-wave vertical antennas are commonly used for broadcast purposes.

The quarter-wave vertical antenna will be used for comparison with newer antenna designs so that it is desirable to define several of the parameters of the quarter-wave radiator. The effective height of a quarter-wave vertical antenna is approximately 0.64 times the physical height. This effective height may be considered as the point at which all current flow can be considered to be concentrated and to secure the same result as the actual distributed condition. The *meter amperes* for a given frequency is this effective height in meters multiplied by the antenna current in amperes (I), and the received signal from the direct ray is directly proportional to this factor ($H_{eff}I$). This is not a measure of power input to the antenna, which is, of course, determined by the product of total antenna resistance measured at the base and the square of the antenna current at the base. The radiation resistance is a function of the effective or useful part of an antenna system, and it is generally desirable to have it high, that is, as high a percentage of the total resistance as possible. The total radiated power is the radiation resistance multiplied by the square of the actual current at the base (I^2R). As pointed out above, a large part of this actual radiated power is wasted in the sky wave.

From this discussion it is evident that a good starting point is to increase the effective height thus increasing the meter amperes radiated. This is accomplished by making the vertical height greater than one-quarter wave. It was shown earlier in Fig. 7-40 that this can be carried almost to the height of a half wave length and still tune to zero reactance by means of a series condenser.

It has been shown¹ that the optimum power efficiency for direct-ray reception will occur at a physical height of the transmitting antenna of 0.62 wave length. This is due to the fact that the next half-wave standing on the wire would be out of phase and would not add to the direct ray. The effect would be that described for long-wire radiators at short waves.

Ballantine shows that a great deal more of the radiated power is concentrated in low-angle radiation. It may be assumed that the ground as a large capacity replaces the lower section of the wave or that the "image" of the upper section is in the earth. Then as the height of the antenna is increased above one-quarter wave, this image becomes of such space phase as to cancel the high-angle radiation without lessening the direct ray.

Most of these designs are carried out in single steel towers pointed at the top and bottom and standing on a single heavy insulator. They are held vertical by means of guys broken up by insulators. When the

¹ BALLANTINE, *Proc. I.R.E.*, December, 1924, p. 833.

tower itself is used as the antenna, the structural members must be carefully bonded (connected together electrically) or special conductors must be run up one corner of the tower and bonded to the tower to reduce resistance losses.

If such an insulated tower is located near an airway, or if it is desired for other reasons to put lights on the tower, the power to operate the lights may be fed to the tower through a low-pass filter system which does not allow the radio frequency from the tower to back up into the power line. Such a filter circuit is shown in Fig. 12-19.

It is often found expensive or impractical to make towers as high as would be required for optimum operation. Such operation is based on a current distribution which places the point of maximum current as close as possible to 0.375 wave length from the base of the radiator. Inasmuch as the point of maximum current is dependent upon the L to C ratio along the length of the conductor or radiator, it is possible to vary this ratio by connecting a lumped capacity, consisting of a network of conductors located at the top of the tower, but usually insulated from it, in series with an inductor also located near the top of the radiator. The series inductance makes it possible to tune the circuit over a wide range. Such a system of lumped capacity and inductance is called a *top-loading system*. One of the largest and most modern broadcasting stations in the United States, the Columbia Broadcasting System's station WABC, New York, N.Y., uses a top-loaded tower. A tower of the required height could not be erected because of the proximity of the station to La Guardia Field, the New York municipal airport, and the hazard such a tower would present to aircraft. Top loading solved the problem. A view of this tower is shown in Fig. 12-20.

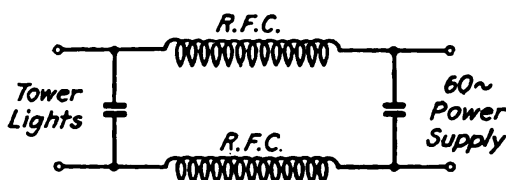


FIG. 12-19.—Low-pass filter for use in line to antenna tower lights.

Another important development is the shunt-excited antenna,¹ which is an arrangement for exciting a vertical broadcast antenna with the base grounded. Construction economy results through the elimination of the base insulator, the tower-lighting chokes, and the usual lightning-protection devices. The coupling apparatus at the antenna end of the transmission line is reduced to a simple series condenser and an inclined conductor running from the coupling house to the tower at an angle of about 45 degrees. Tapping on to the tower at the proper point usually produces a resistance value of less than 100 ohms which is generally correct to match a concentric type of transmission line. Owing to the simplicity of this coupling arrangement, it is unnecessary to build a

¹ MORRISON and SMITH, The Shunt Excited Antenna, *Proc. I.R.E.*, Vol. 25, No. 6, p. 673, June, 1937.

separate building to house the coupling unit, a protective cabin located on a pole being sufficient.

The performance of the shunt-excited antenna is substantially the same as that of the series-excited (insulated tower) type of tower with the advantage of lower construction costs and greater freedom from interruptions resulting from static discharges.

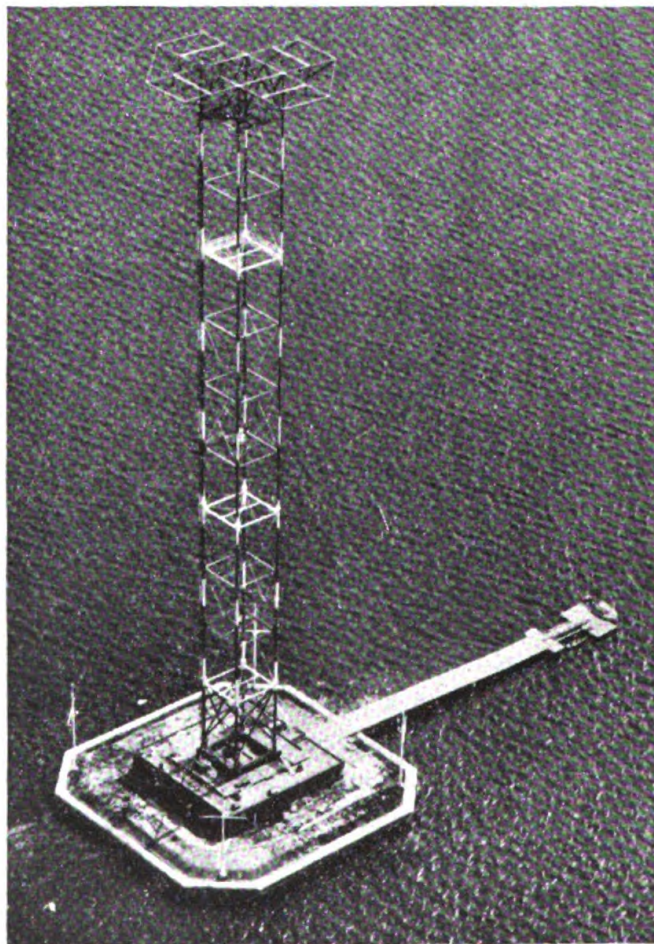


FIG. 12-20.—Top-loaded antenna tower, WABC, New York. (Courtesy of Columbia Broadcasting System.)

The principles of directive antennas as described in Sec. 7.6 are applicable to broadcast antennas and need not be further enlarged on here.

12.11. Broadcast Transmission-line Coupling Circuits.—In high power installations, it is often found desirable to keep the transmitting building out of the more intense radio-frequency field of the antenna. This is accomplished by the use of a transmission line similar to the matched-impedance lines, shown in Fig. 7-16. The coupling circuits used for series-excited antennas are generally different for broadcast work because of the lower frequencies involved. One circuit commonly used with two-wire lines is shown in Fig. 12-21.

The procedure in setting up this circuit is first to determine the proper ratio of the circulating power to the power output of the antenna-coupler tank circuit. The basis for this ratio is not the same as for the plate-tank circuit shown at the left of the diagram. The factors affecting this ratio will therefore now be considered in detail. The plate-tank design was made to eliminate harmonics, and the antenna coupler will also reduce harmonics in proportion to the ratio of circulating watts (VA) to watts output of the tank circuit ($VA/\text{watts output}$). The greater this ratio (especially with the center of the tank condensers grounded as shown in the figure), the lower will be the harmonic content. The limit to which this could be carried would be a point where the higher modulation frequencies are attenuated, owing to the large "flywheel" effect of the tank, and this point is far beyond the range where losses due to high circulating current become prohibitive.

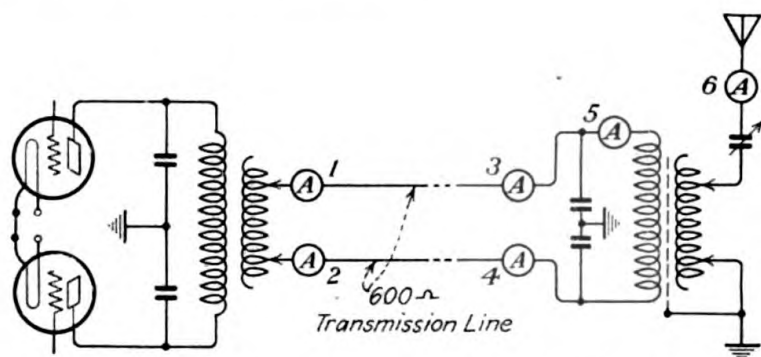


FIG. 12-21.—Coupling circuit commonly used on broadcast frequencies.

Another consideration which affects this ratio is the impedance of the antenna. If the antenna is of high impedance, it makes a greater $VA/\text{watts output}$ ratio desirable, so that the step-up ratio of the coupling to the antenna coil does not have to be too great. In general a slightly higher C/L ratio is used than in the plate tank, but the voltage across the transmission line is comparatively low, so that the $VA/\text{watts output}$ ratio is lower. After this ratio is chosen, the value (C) of the tank condenser may be found from the equation

$$C = \frac{VA}{W_o} \times \left(\frac{10^3}{2\pi f Z_o} \right) \quad (3)$$

where V = effective voltage across transmission line.

A = circulating current in tank circuit.

W_o = watts output.

Z_o = surge impedance.

The value of the inductance may then be calculated from the resonance equation $2\pi fL = 1/2\pi fC$, substituting C as found above. It is best then actually to tune the tank circuit by means of an oscillator.

The following parameters of the coupling circuit are now known: antenna resistance; reflected resistance at the terminals of the tank

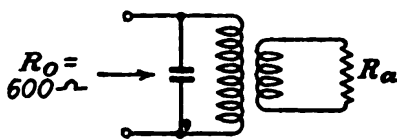


FIG. 12-22.—Equivalent circuit of antenna (R_a) across secondary of antenna coupler.

which is equal to the surge impedance of the line, $R_o = 600$ ohms; capacity of the tank condenser. As the antenna will be tuned to series resonance, it can be assumed that a resistance equal to that of the antenna is connected directly across the antenna side of the coupler, as shown in Fig. 12-22.

It can be shown that the mutual reactance between the two coils of the coupler is given by the equation

$$X_M = \sqrt{\frac{X_c^2 R_a}{R_o}} \quad (4)$$

where X_c = capacity reactance of tank condenser in ohms.

X_M = mutual reactance in ohms.

R_a = antenna resistance in ohms.

R_o = resistance equal to surge impedance of line in ohms.

The next step is to calculate the mutual inductance in microhenrys which will give this mutual reactance. This is accomplished by the equation for reactance:

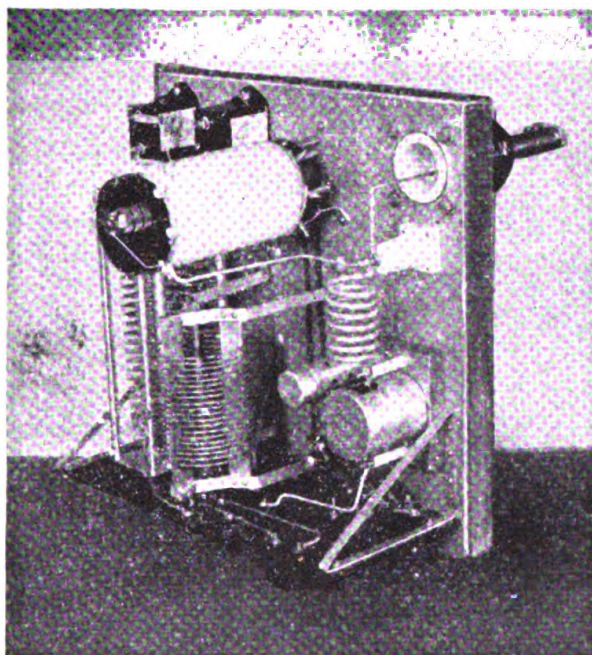
$$X_M = 2\pi f L_M \quad (5)$$

As X_M and f are known, L_M can be found. L_M will be in henrys, so that multiplying by 10^6 will give microhenrys. The desired value of mutual inductance is then known, and it is simply necessary to know the physical dimensions and number of turns to use in the secondary. Empirical formulas 192 or 193, given in the U.S. Bureau of Standards *Bulletin* 74, are convenient for calculating this final stage in the design.

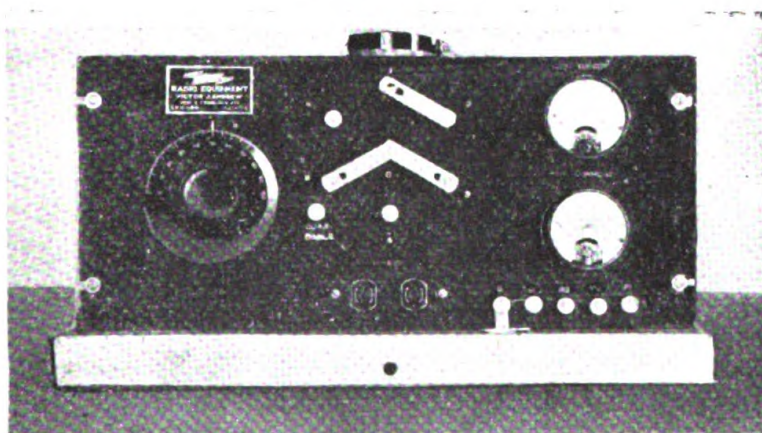
The procedure is then to tune the antenna for maximum antenna current by means of an oscillator using the series-antenna condenser, or a loading coil not inductively coupled to the antenna coupler. The tank condenser is then connected to the primary of the coupler, and the line is connected across the tank. The meters shown in the diagram are to check against reflections on the line and to check the value of the mutual inductance (M) of the antenna coupler. If these line meters read the same on the input to the line as on the output, the impedance may be assumed to be matched. If the current readings are lower at the output of the line than at the coupler, it may be assumed that the antenna coupling is too great. If the readings are higher at the input, the coupling is not tight enough. If it is desired to operate the transmitter into a dummy load, this load may be connected across the transmission line in

the place of the coupler unit, but it must be non-inductive. A good type is the flat resistance-wire element woven on asbestos.

12.12. Application of the Antenna-coupling Unit.—As seen in Fig. 4-1 (c) the output of the radio transmitter may be delivered to the radiating system through a transmission line and the antenna-coupling unit.



(a).—Top view.



(b).—Front view.

FIG. 12-23.—Andrew type 50 antenna-coupling unit. (Courtesy of Victor J. Andrew Co.)

Two views of an actual antenna-coupling unit are shown in Fig. 12-23. This is the Andrews type 50, which serves the following purposes: tunes the antenna; matches the antenna to the impedance of the coaxial transmission line; supplies power to the tower lights. This unit contains a remote-reading antenna ammeter, utilizing a thermionic rectifier.

Figure 12-24 is a schematic diagram of the entire antenna-coupling circuit. In the transmitter, at the left of the diagram, is the output circuit of the second power

amplifier or last radio stage. The split condenser C_1 , C_2 tunes the primary of transformer T_1 . The secondary is tuned by C_3 , and the coupling between the two windings is adjustable to permit the proper amount of resistance to be reflected into the primary circuit and thus to obtain the correct output impedance into which the tubes may work. T_1 may be considered an impedance-matching device for coupling a high-impedance circuit to a low-impedance one, because the combined plate resistance of the two tubes may be as high as 20,000 ohms, while the impedance of the transmission line may be 600 ohms.

The transmission line is merely a link circuit for connecting the transmitter to the antenna-coupling unit. In broadcast stations of 5 kw. or more, it is generally advisable to place the transmitter at some distance from the antenna. This serves a double purpose in that it gets the transmitter building and all associated structures away from the antenna so that there are no large obstructions near it, with a resultant improvement of field patterns; and also the radio transmitter is removed from the intense electric field immediately surrounding the antenna, thereby reducing the possibility of radio-frequency feedback and instability in the transmitter.

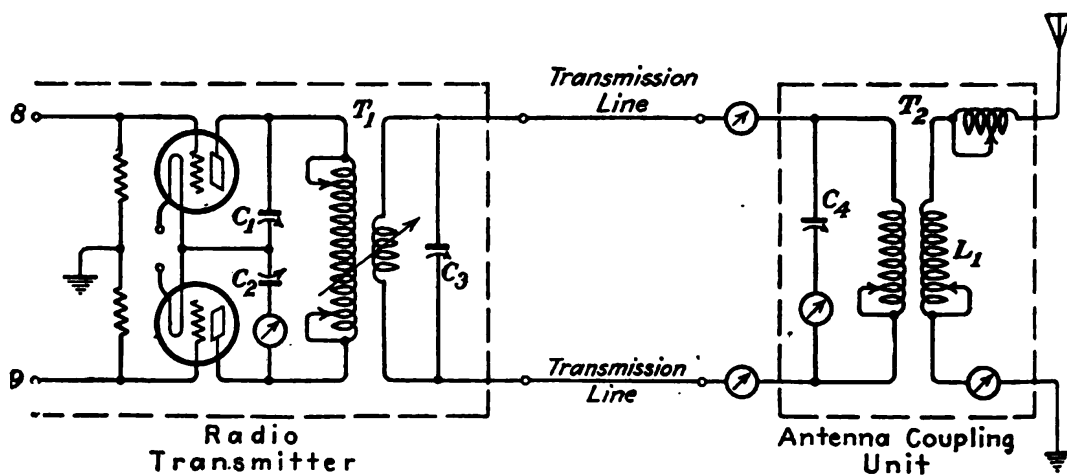


FIG. 12-24.—Schematic diagram of antenna-coupling circuit.

The transmission line is terminated in the coupling transformer T_2 , which is again an impedance-matching device between the line and the antenna-ground system. The primary of the transformer T_2 is tuned to the operating frequency by condenser C_4 . The secondary circuit is tuned by means of coil L_1 and the capacitive reactance of the antenna-ground system. The proper matching impedance for the line is obtained by adjusting the inductance of the secondary L_1 of T_2 , thus changing the mutual inductance and the amount of resistance reflected into the primary circuit. Both windings of T_2 are made of very few turns of large-diameter copper tubing wound on a large-diameter form. This is done to reduce the distributed capacity between turns and to have as little copper as possible, because as a rule the radio-frequency currents are quite high in both circuits. When properly adjusted, all the circuits are tuned to resonance, and the current in each wire of the transmission line is approximately the same. This condition indicates a proper matching of impedances and satisfactory operating results.

Since the output circuit of a tube transmitter must be connected into the proper load impedance to insure the maximum absorption and transfer of power by and to the radiating system, and also a minimum of wave reflection, both the transmission line and antenna impedance must be properly matched.

Where the output of a transmitter is to be fed into a transmission line, the line impedance must be carefully calculated to accommodate the impedance at both the

input and the output of the line. This matched impedance of a line is sometimes referred to as a *surge* or *characteristic impedance*.

In the radio-frequency transmission lines the characteristic impedance of the line must be kept as low as possible, approximately 500 ohms.

The Radiating System.—The antenna and the ground constitute the radiating system of the broadcast station, and this system coupled to the coupling unit and transmission line is the radio-frequency load into which the transmitter operates or delivers power. The antenna forms one plate of a condenser and the ground the other, the intervening space being the dielectric. This large condenser in series with the secondary of the coupling transformer and the loading coil, which tunes the whole circuit to series resonance, constitutes an oscillatory circuit with some value of internal resistance. This circuit, which is tuned to series resonance at the operating frequency, is set into oscillation by the voltages induced in it from the transmitter, and the resulting current flowing through the antenna resistance causes the radio-frequency power delivered by the transmitter to be dissipated in the form of heat and radiated energy.

12.13. Phase Monitors.—When a broadcast station utilizes a directive antenna array, the adjustment of the electrical circuits of such an array requires a series of field-intensity measurements to determine the shape of the field pattern. However, the shape and intensity of this field pattern is a function of the phase and amplitude relations in the elements of the antenna array. In order to check up and measure these phase and amplitude relations, a *phase monitor* is necessary, especially if the station operates on day and night frequencies.

The Western Electric 2A Phase Monitor.—This monitor provides for terminating as many as three sampling lines, originating on small untuned loops on each tower or conductor of the array. These lines may be used on a two-tower array to measure the phase angle between the currents in the two towers and, if desired, the input to a line-branching and phasing network. On a three-tower array, these lines may be used to measure the phase angles between the currents in each pair of towers. A single control is used to select the desired pair. Additional switching facilities will be necessary if more than three towers are involved. This monitor utilizes expanded-scale radio-frequency milliammeters to indicate the true relative amplitudes of the currents in each tower, and a 360-degree scale measures the phase displacement of the tower currents without doubt as to quadrant. On this scale, leading angles are shown in red and lagging angles in black.

Preliminary adjustments for accurate operation on any frequency in the broadcast band can be made without auxiliary apparatus except for a radio-frequency power source of at least $\frac{1}{5}$ watt. The instrument is self-checking and accurate to well within ± 3 degrees. Small changes in angles may be determined with an accuracy of 1 degree, and angles required for established patterns may be set up within 1 degree.

The radio-frequency power required for normal operation is $\frac{1}{5}$ to 4 watts per tower, depending upon the tower-current ratios. The radio-frequency power should be obtained from substantial loops rigidly

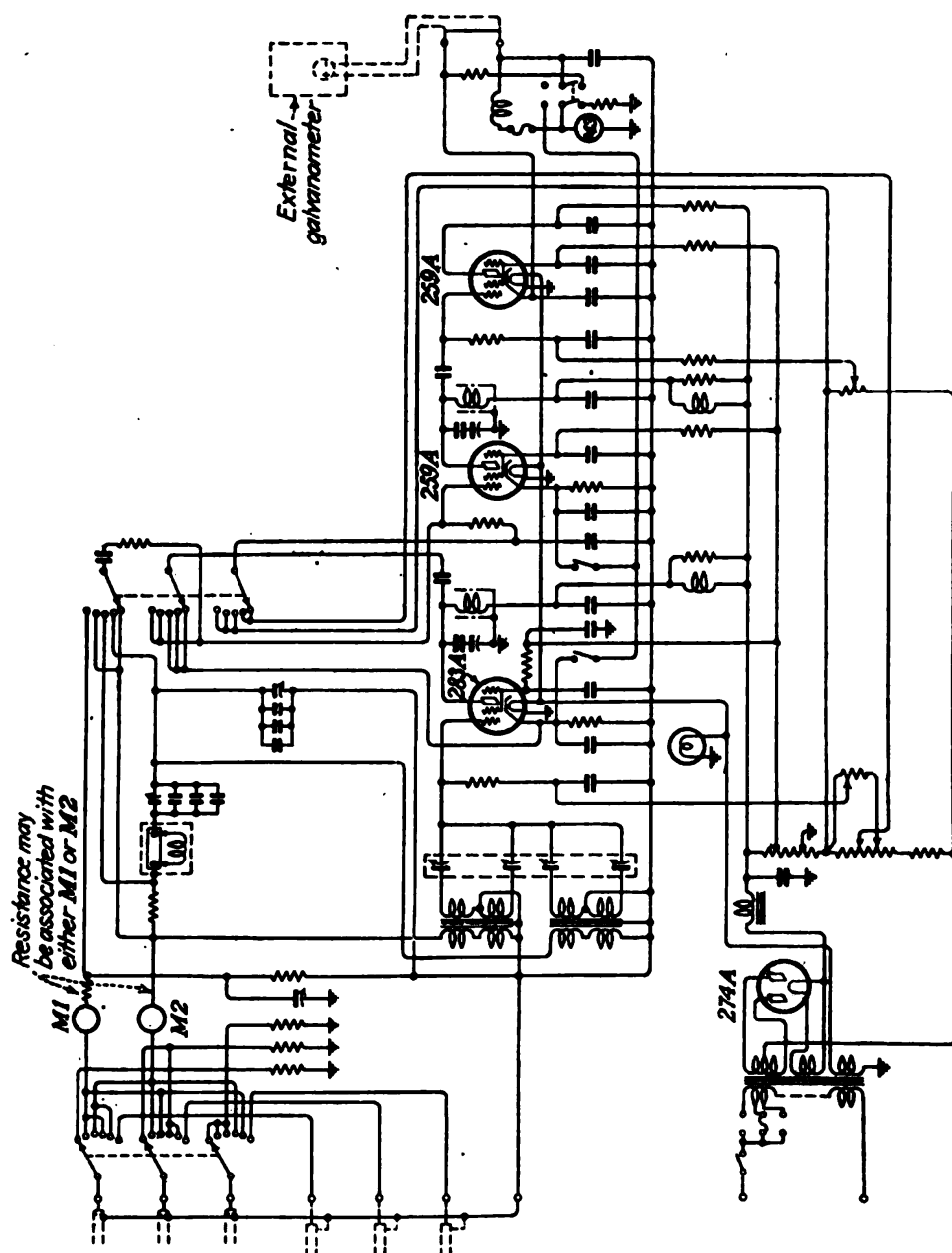


FIG. 12-25. Western Electric 2A phase monitor.

attached to the towers. Because these loops are free from all tuning adjustments, the sampling current remains truly representative indefinitely. Equally simple and reliable means are available for accurately sampling the current in insulated towers.

The 2A phase monitor may be described as consisting principally of the following: two meters for indicating relative amplitudes of tower currents; a phase-measuring condenser and its associated circuit; an amplifier-detector circuit for obtaining an indication of balance; and a self-contained power supply.

The monitor may be quickly installed and adjusted, without the need of external calibrating apparatus. It may be quickly checked at any time when making a measurement. All adjustments are made on the front of the panel. Initial adjustments are independent of the sampling-line currents and the ratio between them. Replacement of tubes does not affect its accuracy. A schematic circuit diagram of this monitor appears in Fig. 12-25. The monitor may be located in any convenient place within the station.

Power is supplied by a self-contained power supply for use on 105 to 125 volts, 40 to 60 cycles, drawing approximately 40 watts. The phase angle range is 0 to 360 degrees. The radio-frequency input impedance is 65 ohms. The minimum radio-frequency input power is $\frac{1}{5}$ watt. The radio-frequency meters have a practically linear range from 50 to 250 ma., making it possible to observe ratios as high as 5 to 1.

This monitor is also adaptable to general laboratory and field measurements. The input impedance, normally 65 ohms, is suitable for connecting to lines of widely varying impedance.

12.14. Antenna-resistance Measurement.—Resistance measurements are generally made for two purposes: (1) to be used in calculation of the antenna-coupling circuits, and (2) for the direct measurement of power output which method is required by the Federal licensing authority. This authority has made the rule that *the resistance which is to be used for this purpose is not to include the resistance of coupling circuits but simply the resistance from antenna post to ground.*

Although there are two methods of measuring antenna resistance, the resistance-substitution and the resistance-variation methods, the latter is chosen to be explained here for the reason that better results can be expected by this method with the high-impedance antennas which are in common use at broadcast stations.

b. A Simple Method for Measuring Antenna Post to Ground Resistance. The Federal licensing authority requires the use of the following apparatus in making these measurements.

1. A radio-frequency generator (oscillator) to cover the required range of frequencies. This generator to have a power output of 50 watts.
2. A wavemeter having an accuracy of 0.25 per cent.

3. A decade resistor box (non-inductive) having steps of units, tens, and hundreds ohms resistance or the equivalent.
4. A radio-frequency galvanometer or milliammeter of an approved thermocouple type (0-100 ma.). This instrument must have an accuracy of 2 per cent.
5. An approved tuning condenser of approximately 0.001 mf. capacity.
6. A tuning inductance of 60 μ h.

Referring to Fig. 12-26, the measurement of the unknown antenna resistance R_a is made by connecting the antenna and ground across the terminals AB with the calibrated

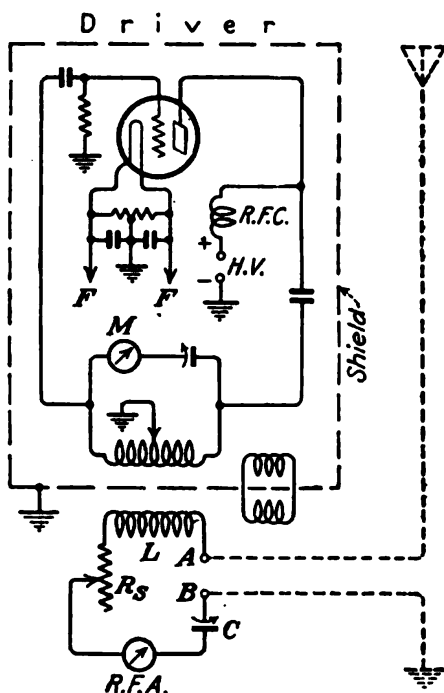


FIG. 12-26.—Circuit setup for measuring antenna resistance.

resistance R_s in zero position. The resistance of the antenna may then be determined by the following procedure:

1. Set the driver into oscillation at the operating frequency, and couple it to the coil through the linking system as shown.

2. Carefully adjust the variable condenser C until a maximum deflection (resonance) is indicated on the radio-frequency ammeter RFA . The coupling between the linking circuit is to be sufficiently loosened so that the reading on RFA is about half scale, or 50 ma.

3. Start increasing the calibrated resistance R_s until the meter reads exactly one-half of its former value, or 25 ma. The amount of resistance introduced by R_s (in ohms) will then equal the antenna resistance R_a .

Note: This same instrument set-up may be used to measure the resistance of radio-frequency coils by connecting the unknown coil resistance R_x , instead of the antenna R_a , across $A-B$.

Precautions: A limitation on the accuracy of the measurement is the existence of e.m.fs. electrostatically induced. In the deduction of the resistance it is assumed that the driver output power remains constant. The virtue of this method is that these stray e.m.fs. may be kept substantially constant during the measurement of the resistance of the circuit by proper grounding. They will invariably be altered by the substitution of the apparatus whose resistance is to be measured, but the resistance of the circuit is measured accurately both with and without the known resistance.

In order to keep these stray e.m.fs. unchanged, when R_s is in, and when it is out of, the circuit, particular care must be given to the grounding of the circuit. The shield of the condenser and the ammeter (particularly if it is a thermocouple with galvanometer) have considerable capacity to ground and are near ground potential. A ground wire, if used, must be connected either to the condenser shield or to one side of the ammeter. If it is connected to the high-potential side of the inductance coil, inaccurate results are obtained. The resistance R_s also must be inserted at a place of low potential, preferably between the shield side of the condenser and ammeter.

Furthermore, as previously stated, care must be taken that the coupling between the measuring circuit and the source is not too close. Otherwise the current in the source, and hence the e.m.f. E , will vary somewhat when R_s is inserted. This will give incorrect resistance values which will depend upon the magnitude of R_s . Whether

such an effect is present can be judged by opening and closing the measuring circuit and noting whether this produces a considerable change in the ammeter reading in the source circuit, or by repeating the measurement with reduced coupling. In order that the measurement can be made using very loose coupling, it is necessary either to have a source of considerable power, or to use a sensitive current-measuring device such as a thermocouple galvanometer.

In the design of broadcast antenna systems there are many other important factors that must be considered and which extend far beyond the scope of this text.

The most important of these, however, may be summarized as follows.

1. The radiating system must be designed to transmit low-angle wave radiation to reduce energy waste due to high-angle or sky-wave radiation. The concentration of the energy into a low-angle or ground-wave propagation increases the local field-strength pattern and reduces sky-wave radiation and subsequent heterodyne interference at remote points. Low-angle radiation is most effectively obtained by the use of a half-wave vertical antenna system. If the half-wave design is impractical for the frequency required, the three-eighth and five-eighth vertical systems may be used. The choice of either of the three systems is primarily dependent upon the frequency at which the antenna system is to be operated.

2. The antenna must be designed within the limits of definite impedance values so that the maximum degree of energy is absorbed and radiated by the system. This is an important consideration since high-impedance antennas introduce too many variables to enable stable operation. The impedance looking into the antenna system must therefore be very carefully determined before transmission lines and coupling units are designed.¹ The antenna resistance does not usually exceed 300 ohms at any of the operating frequencies in the broadcast spectrum. Although it is possible to operate into antennas of high impedance with fair efficiency if the exact impedance can be determined, it is extremely difficult to design accurate coupling devices owing to the uncertainty of the exact antenna-impedance value.

¹ A method of measuring antenna impedance is explained in Sec. 7.19.

CHAPTER 13

MARINE RADIO TRANSMITTERS

Although the title of this chapter indicates that it deals with transmitters, it has been necessary also to include a description of receivers when the transmitter and receiver are built as one unit. This has been done in the lifeboat-radio and coastal-harbor-radiotelephone equipments. The bulk of the chapter, however, deals with transmitters alone as a unit of equipment and from this scope takes its name.

13.1. Radio transmitters for marine use are primarily radiotelegraph transmitters designed to emit either type A1 or A2 emission. The most apparent trend in marine-transmitter design has been the reduction in the size of the transmitter unit for a given power, a standard ship transmitter now being designed for table mounting instead of for mounting on the deck or floor.

Another trend in marine-transmitter design is the use of modern beam power tubes as power amplifiers. Emergency-transmitter requirements are met by operating the main transmitter on a reduced number of tubes from a reserve power source whenever the law permits. Separate emergency transmitters operate from 12-volt storage batteries, simplifying the equipment required.

Marine transmitters are very ruggedly built to withstand hard usage and to reduce the possibility of breakdown. Their size is such as to permit passage through bulkhead doors even for the larger units. Metal parts, as far as possible, are finished to resist attack by salt air and spray. Live circuits are protected against accidental contact with the operating personnel during rough weather by enclosing these circuits, as far as possible, in protective screens and shields. Entry doors to the interior of the transmitters are sometimes fitted with interlocks which cut off high voltages when the door is opened for adjusting or other purposes.

To speed up traffic handling in marine work, transmitters are fitted with break-in systems. Such systems permit the operator to hear signals when his key is up, just as anyone talking on a conventional telephone can receive while transmitting or talking.

Marine transmitters are designed to operate from direct current which is almost always the only power generated aboard ship owing to the self-excitation properties of the direct-current generator.

Frequency stability in a marine transmitter, although important, does *not make* crystal control absolutely necessary even on the high-frequency bands. However, transmitters are built so that they may be easily

switched or converted to crystal control. When not crystal controlled, these transmitters are generally of the master-oscillator power-amplifier type.

Harmonics are suppressed by enclosing oscillating and radiating circuits in shields and by interposing tuned circuits between the oscillator and the antenna. Parasitic oscillations are suppressed by utilizing a minimum number of tubes for the power required and by the use of grid chokes on all tubes.

The power output of the marine transmitter is controlled by the applied plate voltages. Hence, for short-distance work the power may be reduced by reducing the plate voltages. This is nearly always done when testing the transmitter. In this connection, it is important to note that the law requires that only the minimum power required to carry out communications be used at all times in the mobile services.

13.2. Keying Systems.—In order to form the wave emissions from a radio-telegraph transmitter to conform to the characters of the International Morse Telegraph Code it is necessary to start and stop these emissions at will. This is known as *keying* the transmitter and requires special circuit arrangements which must be designed as an integral part of the transmitter.

There are many systems of keying used to meet various conditions. The simplest system perhaps is that employed in the emergency transmitter, shown in Fig. 13-9, where the key is inserted in the primary lead of the plate transformer. This system is well adapted for this transmitter because it uses raw alternating current on the tube plates with its consequently modulated note, and also because only low power is handled. This method is unsuited to higher-powered transmitters using pure direct current on the plates of the tubes because of the e.m.f. inertia in the primary circuit of the transformer which would cause a chirping note to be emitted, and also because the key, in this position, must handle the total current drawn by the transmitter. This method, therefore, is not used except under the conditions encountered in a transmitter such as the type just explained.

The next method, in the order of simplicity, is perhaps that which causes the key to remove a blocking bias from the oscillator tube. A schematic diagram of this method is shown in Fig. 13-1(a). When the key is up, the tube is blocked owing to the grid being negative to the filament by the amount of voltage drop across the resistance *AB*. When the key is down, the tube operates because the grid is at the same potential as the filament, minus only the normal operating bias caused by the drop across the grid leak.

An extension of the method just described is to apply the blocking bias to all the tubes, amplifiers as well as the oscillator. The general scheme is the same as that shown in diagram (a), in which the tube

shown can represent all the tubes in the transmitter. This method is employed in the ET-8010-C transmitter, later described. Another method sometimes employed on low-power transmitters is shown in diagram (c).

Another system of keying is the grid-choke method. In this system, a choke heavy enough to stop oscillation of the tube is placed in the grid of the oscillator tube and is known as the *keying choke*. This choke is

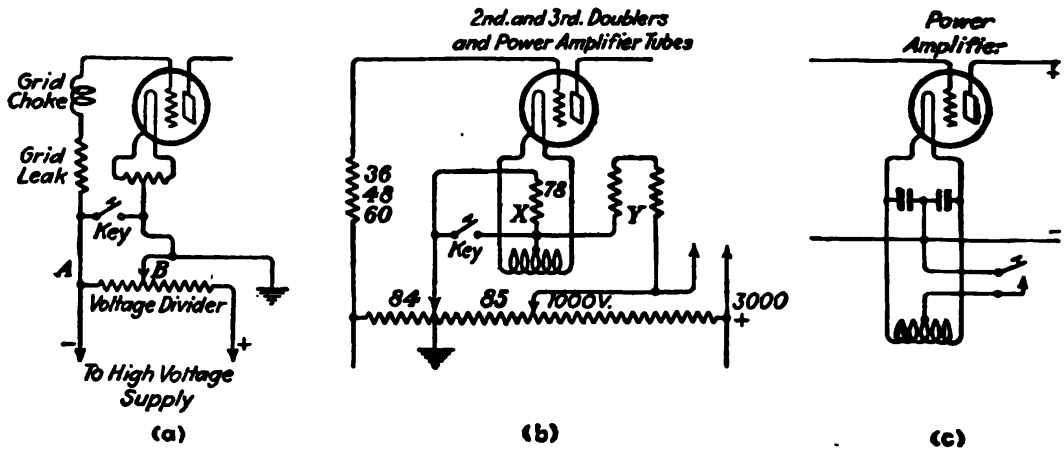


FIG. 13-1.—Various methods of keying a transmitter.

short-circuited when the key or keying-relay contacts are closed, which permits the tube to oscillate; hence keying is accomplished.

In some crystal-controlled transmitters, it may be undesirable to key the oscillator or the buffer amplifier, as to do so might disturb the frequency stability of the transmitter. The practice with these transmitters is to key the stages following the buffer amplifier. This keying circuit is

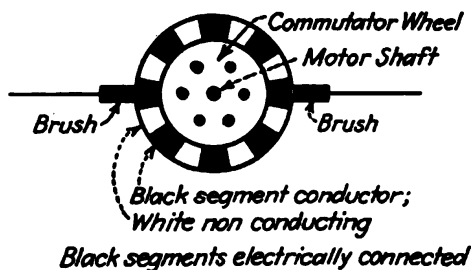


FIG. 13-2.—Chopper, one of the first methods of producing A2 emission.

shown in diagram (b), Fig. 13-1.

13.3. Production of A2 Emission.

Interrupted or modulated (A2)¹ continuous waves are desirable in marine communication because of their greater attention-getting value when stand-by receivers are used. In other words, the receiver does not

have to be tuned so close to the emitted wave in order to have an audible signal get through to the headphones.

One explanation to account for the apparent stability of A2 emission is that, because a relatively wide band of frequencies is radiated (this band width may be twice the highest modulation frequency), the combined effects of fading on the signal as a whole are less pronounced. This

¹A2 emission is prohibited below 30,000 kilocycles except when necessary for emergency communication.

is so because not all the frequencies in the band fade at the same time; hence, a high proportion of the maximum signal energy reaches the receiver constantly.

There are several methods of modifying the continuous wave generated by the oscillator, namely: (1) by means of a chopper in series with the direct-current plate power supply; (2) by means of an audio oscillator; (3) by a conventional plate modulating system. Strictly speaking, only the chopper (Fig. 13-2) interrupts the wave. For this reason, when audio oscillator modulation or conventional plate modulation is used, the emitted wave form is sometimes referred to as *MCW*, meaning modulated continuous waves. The final effect, however, is the same, in that the emitted wave is broadened to cover a wider frequency spectrum.

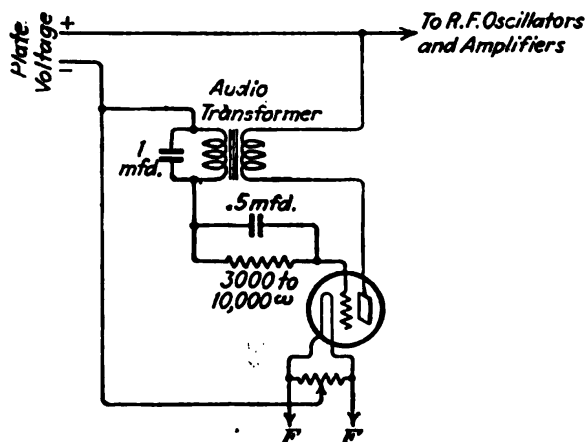


FIG. 13-3.—Audio-oscillator circuit for production of *ICW*.

A schematic diagram of the audio-oscillator system of producing *A2* emission is shown in Fig. 13-3. By studying this circuit, it will be seen that the tube is made to oscillate by feeding back the output from the plate circuit to the input or grid circuit. In this respect, the audio oscillator is not different from the radio-frequency oscillator. The audio oscillator, however, utilizes heavier condensers and larger inductance values. As the frequency of any vacuum-tube oscillator depends on the inductance and capacity in the plate and grid circuits, and as the frequency generated decreases as the value of these constants is increased, large volumes of inductance and capacity are used in the audio oscillator. In order to get the required inductance values, it is necessary to use an iron-core transformer.

The theoretical action of the audio oscillator on the continuous wave is shown by the family of curves in Fig. 13-4. Curve (a) represents the continuous wave generated by the radio-frequency oscillator of the transmitter; curve (b) is the audio-frequency sine wave generated by the audio oscillator and coupled directly to the plate supply of the radio-frequency oscillator and amplifiers. The result is that the audio-frequency wave either adds to or subtracts from the value of the radio-frequency wave, resulting in a modulated half wave as shown in curve (c). Curve (d) shows the resultant

current in the headphone circuit of a receiver using a non-oscillating detector. Notice that the positive pulses of curves (b) and (d) are identical, and that for this reason the received note corresponds to the frequency of the audio oscillator used to produce A2 emission. These waves are also known as *tone-modulated waves*. Antenna current, and consequently transmission range, is generally somewhat less when A2 emission is used than when A1 emission is used.

Of the three A2-wave systems just described, the conventional plate-modulation system is the most modern. It is also the most efficient because the additional power required to create the side bands is supplied from a source independent of the plate power system. Hence, the overall

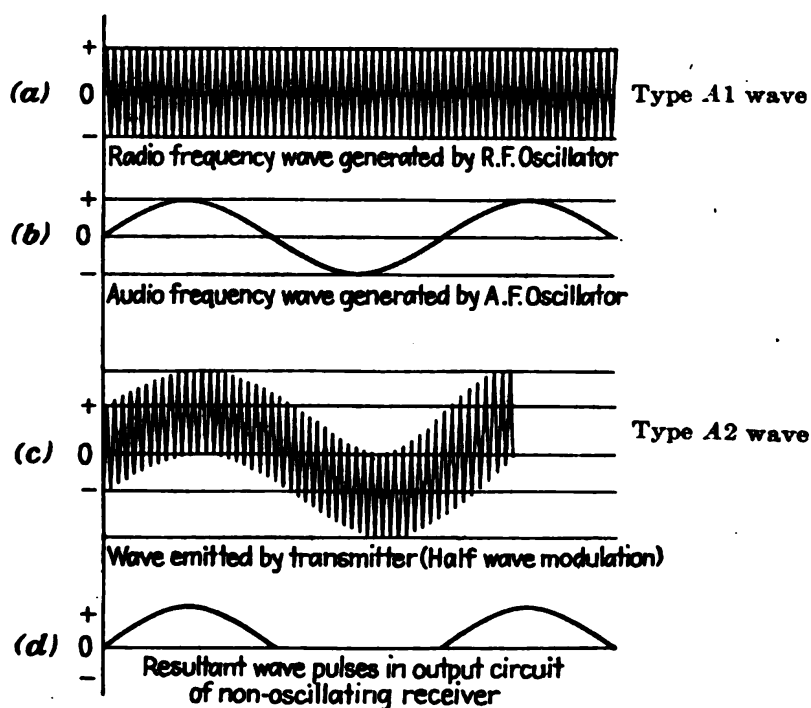


FIG. 13-4.—Action of audio oscillator in producing A2 emission.

efficiency of the transmitter is increased. This system is used in the R.M.C.A. model 8010-C transmitter shown in Fig. 13-7 and will probably be widely adopted in other transmitters designed for A2 emission.

The theoretical action and a wiring diagram of the fundamental circuit employed for producing A2 emission by the conventional plate-modulating system is shown in Fig. 13-5. Curve (a) shows the carrier before and after modulation is applied. The modulating voltage is supplied at 110 volts, 500 cycles from a separate alternator winding on the motor generator and introduced to the plate circuit through the modulation transformer as shown in the diagram. This modulation is applied to the final radio-frequency power amplifier and is, therefore, high-level modulation.

Curve (b) shows the modulating frequency which is added to and subtracted from the carrier frequency alternately. The modulation secured is approximately 90 per cent complete. The radiated power is

considerably increased over that which is obtained with the audio-oscillator system of modulation, which was the modern system until this more efficient system of high-level modulation was adopted.

Curve (c) shows the resultant wave pulses in the output circuit of a non-oscillating receiver tuned to respond to this high-level system of modulation. It will be noted that for each cycle of modulation voltage a pulse of output voltage is produced, resulting in a 500-cycle tone in the output signal.

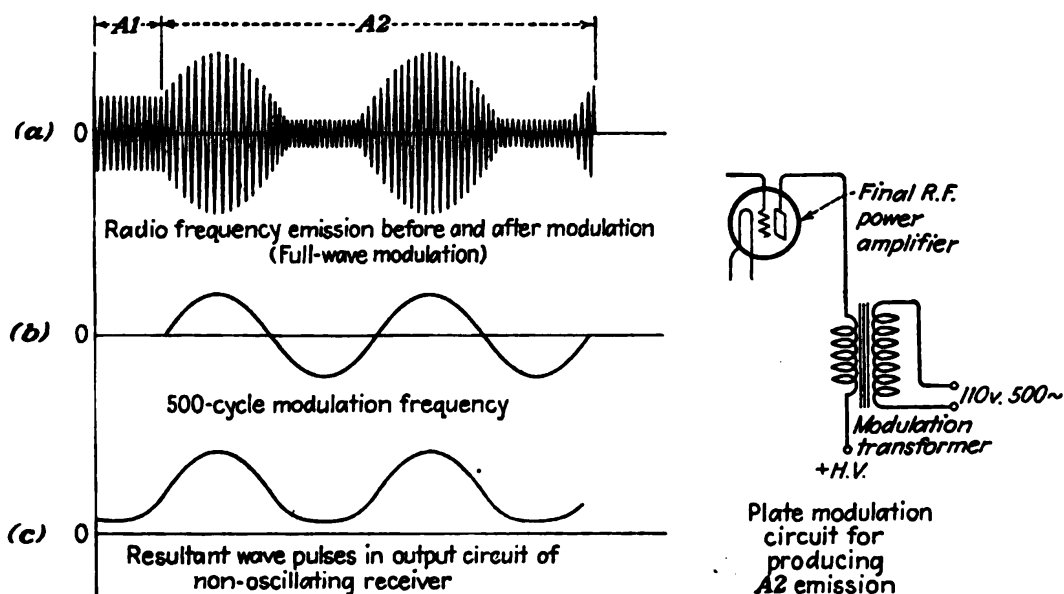


FIG. 13-5.—Theoretical action and circuit for plate-modulation method of producing A2 emission.

13.4. Medium-frequency Transmitters.—This class of transmitter is basic equipment for all compulsorily equipped ships. The medium frequencies are used for all except long-distance communication. Both the ship's main and emergency transmitters are medium-frequency transmitters. However, in this section only the types suitable for use as a *main transmitter* will be discussed. Emergency transmitters will be discussed as a separate class of transmitter in the next section.

1. R.M.C.A.¹ MODEL ET-8010-C. *a. General Description.*—This transmitter, shown in Fig. 13-6, is designed primarily for marine applications where a compact medium-power transmitter is required. The design of this equipment embodies several features not heretofore available, such as quick selection of operating frequencies, plate modulation of the power amplifiers for A2 emission (modulated telegraphy), and the use of high-efficiency iron-core litz inductances.

b. Rating.—The transmitter is designed to deliver 200 watts or more to a standard 750 mmf. 4-ohm antenna, modulated at least 70 per cent,

¹ Radiomarine Corporation of America, a Radio Corporation of America service.

for modulated telegraphy (A2) and 160 to 200 watts for continuous-wave transmission (A1). A schematic circuit diagram is shown in Fig. 13-7.

c. Frequency Range.—The design permits the set to be pretuned to any eight frequencies in the band 350 to 500 kilocycles (857 to 600 meters). The actual operating frequencies for which the transmitter is tuned appear on the frequency switch, and in case it is desired to set up

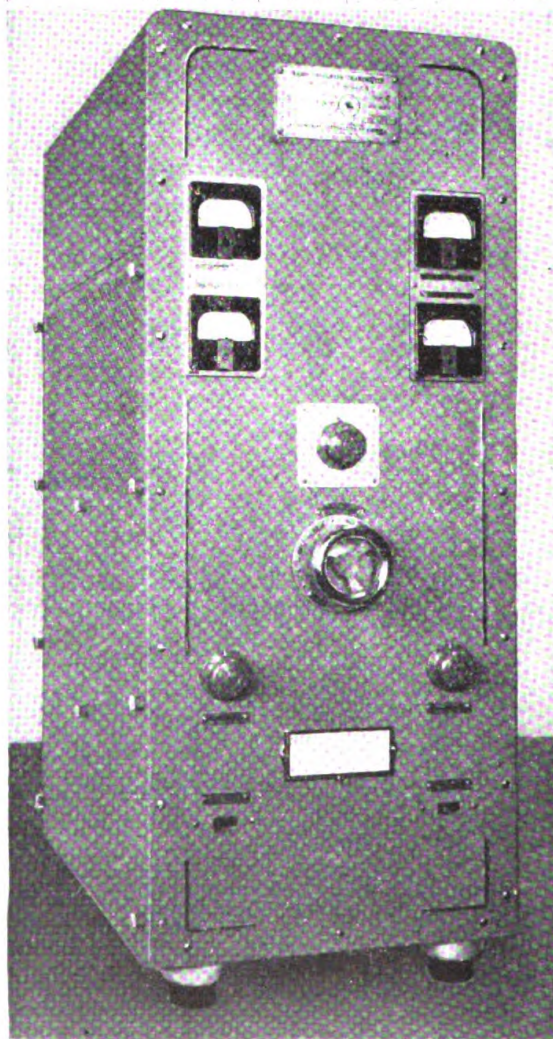


FIG. 13-6.—R.M.C.A. Model ET-8010-C medium-frequency radiotelegraph transmitter. (Courtesy of R.M.C.A.)

the transmitter for different frequencies within the specified range, removable name plates are provided. Name plates are available for the following frequencies: 355, 375, 400, 410, 425, 454, 468, 500 kilocycles. For ordinary service, the transmitter is usually tuned to 355, 375, and 500 kilocycles and five additional working frequencies within the band. The transmitter is designed for crystal control or master-oscillator control of frequency. To change to crystal control, it is merely necessary to remove

a small capacitor and place the crystal holders on the mounting board provided.

d. Vacuum Tubes.—Four tubes are used in the transmitter. The master or crystal oscillator uses one 807 tube. The buffer amplifier stage also uses one 807 tube. The power amplifier utilizes two 211 tubes in parallel.

e. Power Supply.—The transmitter is designed for 115 or 230 volts direct-current supply, and the appropriate motor-generator set for the line supply voltage is included as part of the equipment. The motor-generator set is a three-unit two-bearing machine, consisting of a direct-current motor with slip rings for filament supply, a 1,200-volt direct-current generator for plate supply, and a 500-cycle alternator for modulated telegraphy (A2). For 115-volt direct-current supply, the motor-generator set is rated as follows: Motor—type LF/53, 110 volts, 11 amp. direct current, 2,500 r.p.m. with slip rings to deliver 75 volts, 1.33 amp., at 83 cycles. High-voltage generator, 1,200 volts, 0.45 amp., direct current, alternator 110 volts, 1.59 amp. at 500 cycles. The 230-volt motor-generator set is rated the same as the 110-volt unit, except for the motor which is rated 240 volts, 5 amp. direct current with slip rings to deliver 165 volts, 0.6 amp. at 83 cycles. Alternating-current-drive motor generators may be supplied if necessary.

f. Type of Circuit.—The transmitter utilizes a master-, or crystal-, oscillator buffer-amplifier power-amplifier circuit with plate modulation on the power-amplifier tubes through a modulation transformer for A2 or modulated telegraphy. The oscillator circuit contains eight small adjustable inductances for the eight spot frequencies. These coils are wound with litz wire and have an adjustable iron core for varying inductance. A similar circuit arrangement is used for the buffer and power amplifiers. A special five-pole eight-position switch is used to select the appropriate circuits for the eight spot waves. The power amplifier is coupled to the antenna circuit by means of relatively high-capacity condensers which are in series with the power-amplifier tank circuit so that a minimum amount of harmonic power is transferred to the antenna system. The antenna circuit is tuned by means of a variometer and a tapped loading coil, the taps being automatically selected by the frequency switch. Break-in operation is provided by means of a special break-in relay.

g. Antenna Characteristics.—The transmitter is designed to cover the specified frequency range on any antenna whose characteristics fall between 500 and 1,500 mmf. with a resistance of 4 to 10 ohms.

h. Installation.—The transmitter should be installed so that both side panels may be removed for tube replacements and for adjusting the oscillator, buffer, and power-amplifier inductances. One or two brackets should be made up on the job and fastened to the frame of the transmitter somewhere near the top and then run to the bulkhead through Lord shock mounts. The shock mounts are usually fastened to the bulkhead,

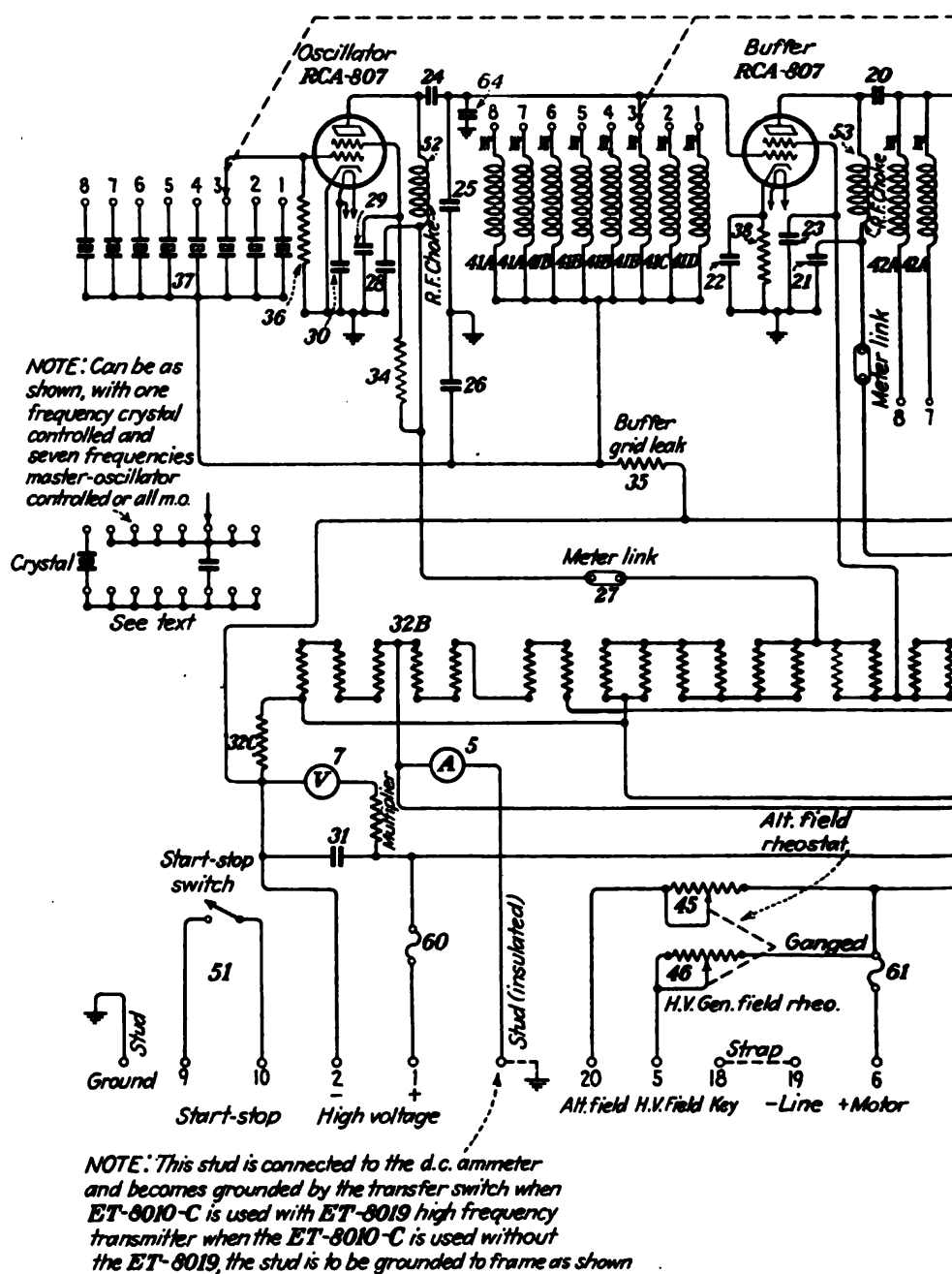
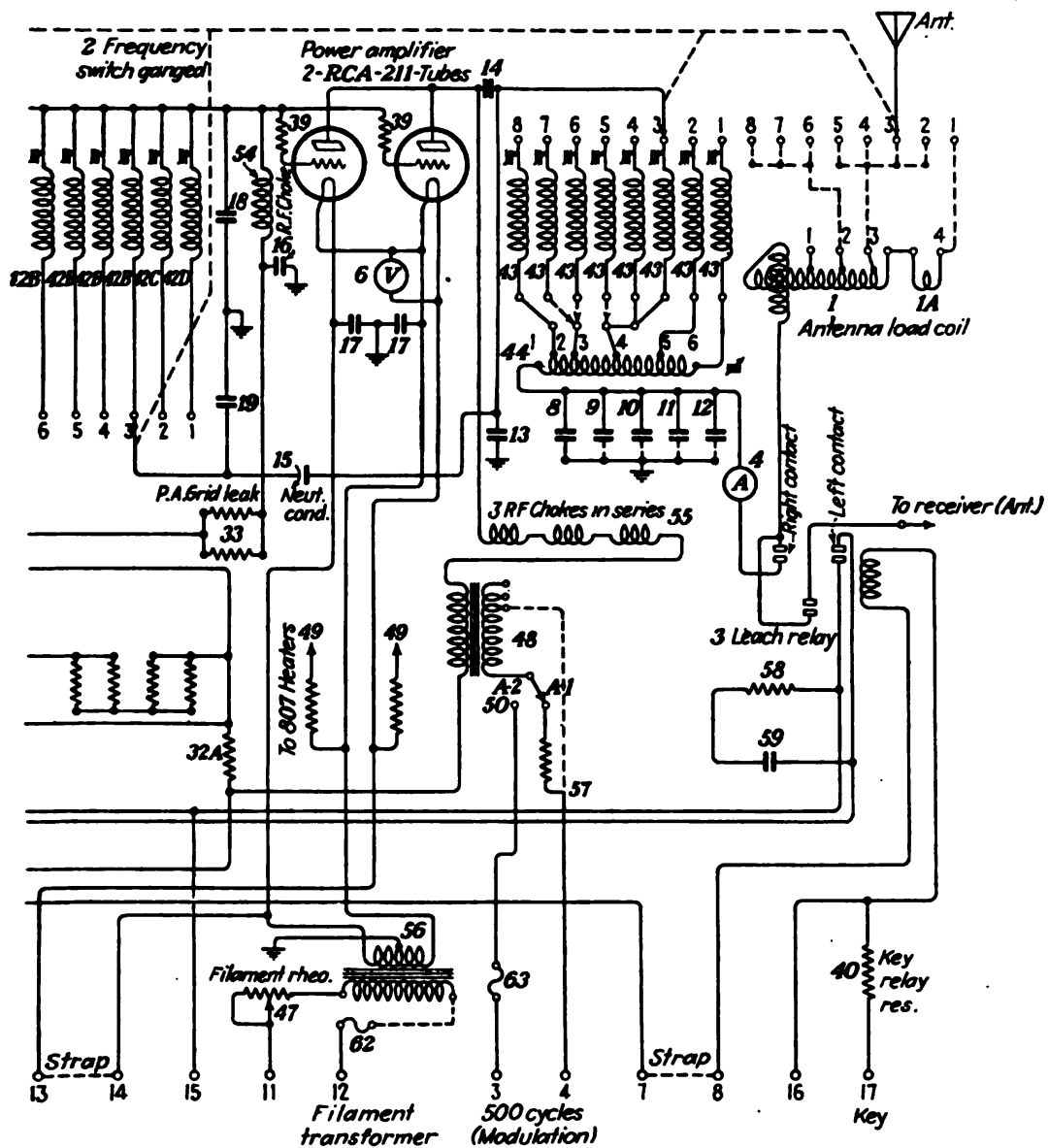


FIG. 13-7.—R.M.C.A. Model ET-8010-C



medium-frequency radiotelegraph transmitter.

and a right angle is bent on the supporting brackets where they connect between the mount and the transmitter. The upper portion of the transmitter is enclosed with Bakelite and not metal, to reduce losses, and for this reason the bracket must be fastened to the frame and not to the Bakelite panel material. Unless these brackets are used, there will be excessive movement of the transmitter under conditions of shipboard vibration. The tuning inductances are provided with lock nuts which should be securely locked in place after the proper adjustment has been made. No. 12 B. and S. wire should be used for the motor circuits and No. 14 B. and S. for all other power circuits. Standard 600-volt insulation should be used on all wiring except the 1,200-volt generator positive lead, which should use 5,000-volt insulation. An 0.1-mf. condenser should be mounted externally across the key contacts to suppress clicks.

i. Transmitter Adjustments.—The transmitter is normally adjusted at the factory for the following frequencies: No. 1, 355; No. 2, 375; No. 3, 400; No. 4, 410; No. 5, 425; No. 6, 454; No. 7, 468; No. 8, 500 kilocycles. Numbers one to eight correspond to the crystal mounting positions, the oscillator variable inductance adjustments, the buffer-amplifier inductance adjustments, and the power-amplifier trimmer inductance adjustments. All the above circuits are tuned from the right side of the vertical subpanel which is made accessible by removing the right side panel of the transmitter. Two meter links are provided so that milliammeters may be inserted in the oscillator and buffer-amplifier plate circuits. These links consist of two binding posts with a strap normally connected between them which is to be removed when metering and replaced after all adjustments are made. Each link is suitably marked. The meter used for the oscillator link need be no larger than 15 ma. and should not be so large that it is difficult to read small changes in the order of 1 ma. The milliammeter used for the buffer-amplifier plate-current link should have a range of approximately 0 to 100 ma. The main plate-current meter on the front panel reads all plate currents, but since the oscillator and buffer plate currents are relatively low, this meter conveniently indicates proper power-amplifier plate-circuit resonance. The transmitter is normally adjusted for the aforementioned frequencies using the oscillator as a master oscillator. If any changes are necessary from the frequencies to which the transmitter is normally tuned, the following procedure should be used.

1. Disconnect antenna from transmitter, and remove both right and left side panels.
2. Couple the pickup coil of the frequency meter as loosely as necessary to the power-amplifier tank inductance.
3. Loosen all the locking nuts on the threaded rods extending through the vertical subpanel for the frequency to be readjusted.
4. Turn the plate-voltage rheostat to the extreme counterclockwise position so that the generator voltage is about 700 volts.
5. Adjust the filament voltage to 10 volts.
6. Assuming the 454-kilocycle setting is to be adjusted, these are the No. 6 adjustments in the various stages: Connect milliammeters in the oscillator and buffer plate circuits. Disconnect the filament lead to the power-amplifier tubes by temporarily removing the wire nearest the left-hand side of the set, which goes to the filament terminals on the sockets. This enables the plate-filament capacity of the power-amplifier tubes to remain in the circuit when adjusting the buffer, but prevents power-amplifier plate-current flow and unloads the buffer so that a sharp dip is obtained when adjusting the buffer. Adjust the plate voltage to approximately

700 volts. Now, if the set is master-oscillator controlled, adjust the iron core in the oscillator coil until the correct frequency is obtained. If the set is crystal controlled, adjust the iron core in the oscillator until you get a single dip with an oscillator plate current of about 5 ma. If more than one dip is observed, with crystals, the plate current will be considerably higher than 5 ma., which is an indication that the iron core is greatly beyond its correct position.

After the correct dip is determined in the oscillator, move the core screw counter-clockwise about one-quarter to one-half turn, which will raise the oscillator plate current 1 or 2 ma. higher than minimum. Next, adjust the iron core in the buffer stage for a true minimum, which will be between 5 and 10 ma. with 700 plate volts.

PARTS OF R.M.C.A. MODEL ET-8010-C TRANSMITTER (See Fig. 13-7)

1. Antenna loading coil.
2. Frequency switches, ganged.
3. Keying relay, Leach type 212.
4. Plate-current meter, 0-12 amp.
5. D.-C. ammeter, 0-1 amp.
6. A.-C. voltmeter, 0-15 volts.
7. D.-C. voltmeter, 0-1.5 kilovolts.
8. Power-amplifier tank condenser, 0.012 mf.
9. Power-amplifier tank condenser, 0.005 mf.
10. Power-amplifier tank condenser, 0.004 mf.
11. Power-amplifier tank condenser, 0.002 mf.
12. Power-amplifier tank condenser, 0.001 mf.
13. By-pass condenser, 0.001 mf.
14. Plate-current stopping condenser, 0.002 mf.
15. Neutralizing condenser, 150 mmf.
16. By-pass condenser, 0.01 mf.
17. By-pass condensers, 0.01 mf., each.
18. Buffer tank condenser, 0.001 mf.
19. Buffer tank condenser, 0.004 mf.
20. Plate-current stopping condenser, 0.002 mf.
21. By-pass condenser, 0.01 mf.
22. By-pass condenser, 0.01 mf.
23. By-pass condenser, 0.01 mf.
24. Plate-current stopping condenser, 0.002 mf.
25. Oscillator-tank condenser, 0.001 mf.
26. Oscillator-tank condenser, 0.004 mf.
27. Meter link.
28. By-pass condenser, 0.01 mf.
29. By-pass condenser, 0.01 mf.
30. By-pass condenser, 0.01 mf.
31. Filter condenser, 4 mf.
- 32A. Buffer plate-voltage dropping resistor, 5,000 ohms, 100 watts.
- 32B. Main voltage divider, group of twenty-one 5,000-ohm resistors, 5 watts each.
- 32C. Resistor, 200 ohms, 100 watts.
33. Power-amplifier grid leak, 10,000 ohms, 5 watts each.
34. Oscillator screen grid resistor, 50,000 ohms, 2 watts.
35. Buffer grid leak, 100,000 ohms, 2 watts.
36. Oscillator grid leak, 100,000 ohms, 2 watts.
37. Oscillator crystals for eight frequencies.
38. Buffer cathode resistor, 500 ohms, 3 watts.
39. Antiparasitic resistors, 15 ohms each.
40. Key relay resistance, 300 ohms for 110-volt line, 750 ohms for 230-volt line.
41. Oscillator plate tank inductances, eight coils.
42. Buffer plate tank inductances, eight coils.
43. Power-amplifier plate tank inductances, eight coils.
44. Power-amplifier plate-tank tuning inductance.
45. Alternator field rheostat, 378 ohms for 110-volt line, 1,500 ohms for 230-volt line.
46. High-voltage generator field rheostat, 585 ohms for 110-volt line, 2,510 ohms for 230-volt line.
47. Filament rheostat, 25 ohms for 110-volt line, 75 ohms for 230-volt line.
48. Modulation transformer.
49. Series resistors to 807 tube heaters, 1 ohm, 20 watts.
50. Emission switch, A1 or A2 emission.
51. Start-stop switch.
52. Radio-frequency choke coil.
53. Radio-frequency choke coil.
54. Radio-frequency choke coil.
55. Radio-frequency choke coils, three coils in series.
56. Filament transformer.
57. Resistor, 75 ohms, 20 watts.
58. Key click dissipating resistor, 500 ohms, $\frac{1}{2}$ watt.
59. Key click absorbing condenser, 0.1 mf.
60. High-voltage fuse, 0.8 or 0.75 amp.
61. Power line fuse, 3 amp.
62. Filament line fuse, 3 amp.
63. A2 modulation line fuse, 3 amp.
64. By-pass condenser, 0.001 mf.

Now reconnect the power-amplifier filament circuit permanently, disconnect the antenna, and tune the power-amplifier iron core for minimum plate current, which will be about 60 to 80 ma. on the panel plate ammeter with 700 plate volts. Connect antenna, raise plate voltage to its normal full-power value, and tune antenna for maximum antenna current. If it is necessary to change the value of the antenna-coupling condensers to load out the power amplifier properly, *keep in mind* that a change in antenna-coupling capacity detunes the power-amplifier tank slightly and,

therefore, the power-amplifier iron core should be readjusted for a true minimum, with antenna disconnected, each time the antenna-coupling capacity values are changed.

In the case of master-oscillator sets, when checking the beat note, the note will of course change continuously whenever the oscillator iron core is moved. In checking for stability of crystal-controlled sets, with the correct oscillator adjustment the note will not change perceptibly when the core is properly adjusted. With crystals, if the core is moved clockwise, the crystal will lose control and the circuit will act as a master oscillator, whereas if the core is moved counterclockwise the crystal will "lock in," and then if the core is moved slightly more counterclockwise the keying should be clean and crystal controlled.

7. The antenna-coupling capacitors are five units mounted to the right of the break-in relay and are rated 0.005 mf. UC-3029-Yk, 0.004 UC-3037, 0.002 UC-3053, and 0.001 UC-3070. These five condensers are mounted over the large 0.012-mf. UC-3276 condenser. The UC-3276 condenser must always be left in the circuit. For a low-resistance antenna, all five coupling condensers should be connected in parallel. For the average 4-ohm antenna, three or four of the five condensers should be connected in parallel to the 0.012 UC-3276 unit. When the proper antenna-coupling capacity has been determined and with the power-amplifier tank circuit properly resonated, the set should load up to approximately 0.45 amp. with 1,200 plate volts. When adjusting the antenna coupling, keep in mind that the more coupling capacity is used the lower will be the coupling and the lower the input, while the opposite effect takes place as the coupling capacity is reduced.

8. The antenna variometer has four stator taps. Counting from the rotor we refer to the taps as No. 1, No. 2, No. 3, and No. 4. When the transmitter leaves the factory, these stator taps are terminated to the selector switch points necessary for an average antenna of 750 mmf. and 4 ohms.

9. The inductance section of the power-amplifier plate circuit is composed of a main coil with taps and provided with an iron core which is adjusted at the factory, together with eight trimmer inductances, any one of which may be inserted in series with the main coil, depending upon the position of the frequency switch. The main power-amplifier tank coil is mounted vertically at the rear of the power-amplifier tubes. The adjustment of the iron core for this coil is made at the factory, and there should be no occasion to change it. With the left side panel removed, it will be observed that the main power-amplifier tank coil is provided with six taps. The lower end of this coil connects to the antenna-coupling capacitors, whereas the taps connect the various trimmer inductances. The No. 1 trimmer, for 355 kilocycles, connects to the top terminal of the main tank coil. The No. 8 trimmer connects to the second tap from the bottom end of the main tank. The five working-wave power-amplifier trimmers connect to the main coil (item 44) as shown on the diagram.

The power-amplifier neutralizing condenser is set and locked at the factory and uses approximately four-fifths of its maximum capacity.

10. If the ship's radio receiver is used to check the note, and overload of receiver due to a strong signal makes this difficult, it is suggested that the receiver be tuned to one-half the frequency of the transmitter. For example, if 500 kilocycles is being checked, tune the receiver to 250 kilocycles. This will enable the second harmonic of the receiver to beat the transmitter fundamental frequency and will avoid receiver overload.

j. General Operating Instructions.

1. Do not exceed 1,200 volts or 0.45 amp. plate input.
2. Always keep the filament voltage adjusted to 10 volts.
3. Keep all shields of the transmitter fastened tightly to the frame.

4. Keep break-in relay contacts adjusted with minimum clearance for best keying. When this relay is properly adjusted, no sparking should occur on the right pair of antenna contacts and only slight sparking should be observed on the left pair or power contacts. Make sure that the lower contacts, which connect the antenna circuit to the receiver, are always open when the relay coil is energized.

5. Keep the transmitter and motor generator free from dust and oil. Occasional dusting of the transmitter and all name plates on the panel will help maintain new appearance. The Isolantite switches in the tank circuits and antenna circuits should be cleaned about every 6 months of accumulations of dirt and dust which might cause flashover. Do not use any form of polish on chromium trim or name plates.

k. Installing Crystals.—Crystal holders should be installed on the mounting board so that the RCA monogram on the holder is *nearest* the front panel or the left side panel.

If a total of eight crystals are used, it is necessary to remove the 0.002 condenser from the crystal mounting board and also unsolder the paralleling strap connection on the board that is *nearest* the frequency switch (not the strap connection near the front panel).

If less than eight crystals are used, it is necessary to parallel the connection studs and connect the 0.002 condenser *for those frequencies* which are to be master-oscillator controlled. For example, one crystal controlled and four master-oscillator frequencies could be used as shown in the diagram.

R.M.C.A. MODEL ET-8010-CA. *a. General Description.*—The ET-8010-C transmitter previously described is designed so that by the addition of an emergency power panel and a small dynamotor the ET-8010-C may be used both as a main and as an emergency transmitter when permitted by law. The transmitter is designated as ET-8010-CA when equipped with emergency power apparatus. The same circuits are utilized throughout, the only difference being that, for emergency operation, one power-amplifier tube is disconnected and the plate supply is obtained from a small emergency dynamotor which is driven by a 12-volt storage battery. A suitable 12-volt storage battery, to provide 6 hr. emergency operation, should have a capacity at the 6-hr. rate, of 256 amp.-hr. A 17-plate battery is usually employed for this purpose.

b. Rating.—The rating of the equipment when used as a main transmitter is specified in the first part of this description. When used as an emergency transmitter, the input to the final stage is greater than 100 watts, and the output is 50 or more watts into the antenna circuit when used with a standard 4-ohm 750-mmf. antenna.

c. Frequency Range.—Any one of eight spot frequencies for which the main transmitter is adjusted may also be used when the transmitter is operated from the emergency power supply.

d. Vacuum Tubes.—The same vacuum tubes are used with the exception that, in order to conserve battery drain, only one power-amplifier tube (RCA-211) is used when the transmitter is functioning from the emergency supply.

e. Power Supply.—The rating of the emergency dynamotor type MT4/KS1 is as follows:

Motor— $\frac{1}{3}$ hp. 11.5 volts, 28 amp. direct current, 2,500 r.p.m., compound wound.

Generator—575 volts, 0.25 amp. direct current, compound wound.

Alternator—55 volts, 0.91 amp., single phase, 500 cycles.

When the transmitter is used with emergency power supply, the 12-volt line current required is approximately 37 amp.

f. Installation.—Installation should be carried out much the same as for the regular ET-8010-C transmitter. The emergency-power panel should be located close to the operating position, since the START-STOP switch for the emergency dynamotor is on the panel of this apparatus. The emergency-power panel includes a 0- to 20-volt direct-current battery voltmeter and a 0- to 20-amp. direct-current ammeter to indicate battery charging current. At the center of the panel the switches are from left to right: emergency START-STOP, battery CHARGE-DISCHARGE, and trickle charge ON-OFF. Directly above this line of switches is the power-transfer switch which is a gang consisting of five double-pole double-throw tumbler switches and one special-design high-voltage transfer switch.

Charging resistors are mounted at the rear and consist of four rib-flex resistors of 1.37 ohms each, making a total of 5.48 ohms for charging at the regular rate and one trickle-charge resistor of 200 ohms which is shorted out by the trickle-charge switch when it is in the OFF position. A small external-resistor cage containing four 1.37-ohm rib-flex resistors (total resistance 5.48 ohms) is used when the ship's line is 110 volts direct current. An additional cage containing eight 1.37-ohm rib-flex resistors is used if the ship's line supply is 240 volts direct current.

In the bottom section of the emergency-power panel, there will be found an adjustable resistor which is used in series with the filament supply to the transmitter. The purpose of this resistor is to reduce the voltage from the 12-volt storage battery to a suitable value for the tubes in the transmitter. This resistance should be adjusted, during installation, so that the filament voltmeter on the transmitter reads 10.5 volts when the dynamotor is running and with the key closed. This 10.5-volt setting is recommended so that as the battery voltage falls during discharge the tubes will still obtain their normal filament voltage.

The lower front panel of the emergency power panel is removable to provide easy access to the four fuses, namely, one 60-amp. line fuse for the 12-volt emergency dynamotor, two 30-amp. battery-charging line fuses, and the small 6-amp. glass fuse used for the emergency radio-room light. Four heavy studs are provided for the heavy battery and dynamotor input leads which should be run with No. 4 wire. These heavy terminals are reached from the bottom of the unit, and all other terminals are available when the lower section of the front panel is removed.

When installing the external battery-charging resistors, care should be taken to locate them so that they are adequately ventilated and so that

they are not so close to the normal operating position as to inconvenience the radio operator.

g. Operation.—In case of failure of the ship's main power supply, the radio operator should observe the following procedure to operate the transmitter under emergency conditions:

1. Throw CHARGE-DISCHARGE switch to DISCHARGE position.
2. Throw POWER-TRANSFER switch to EMERGENCY-POWER-SUPPLY position.
3. Start dynamotor with START-STOP switch.

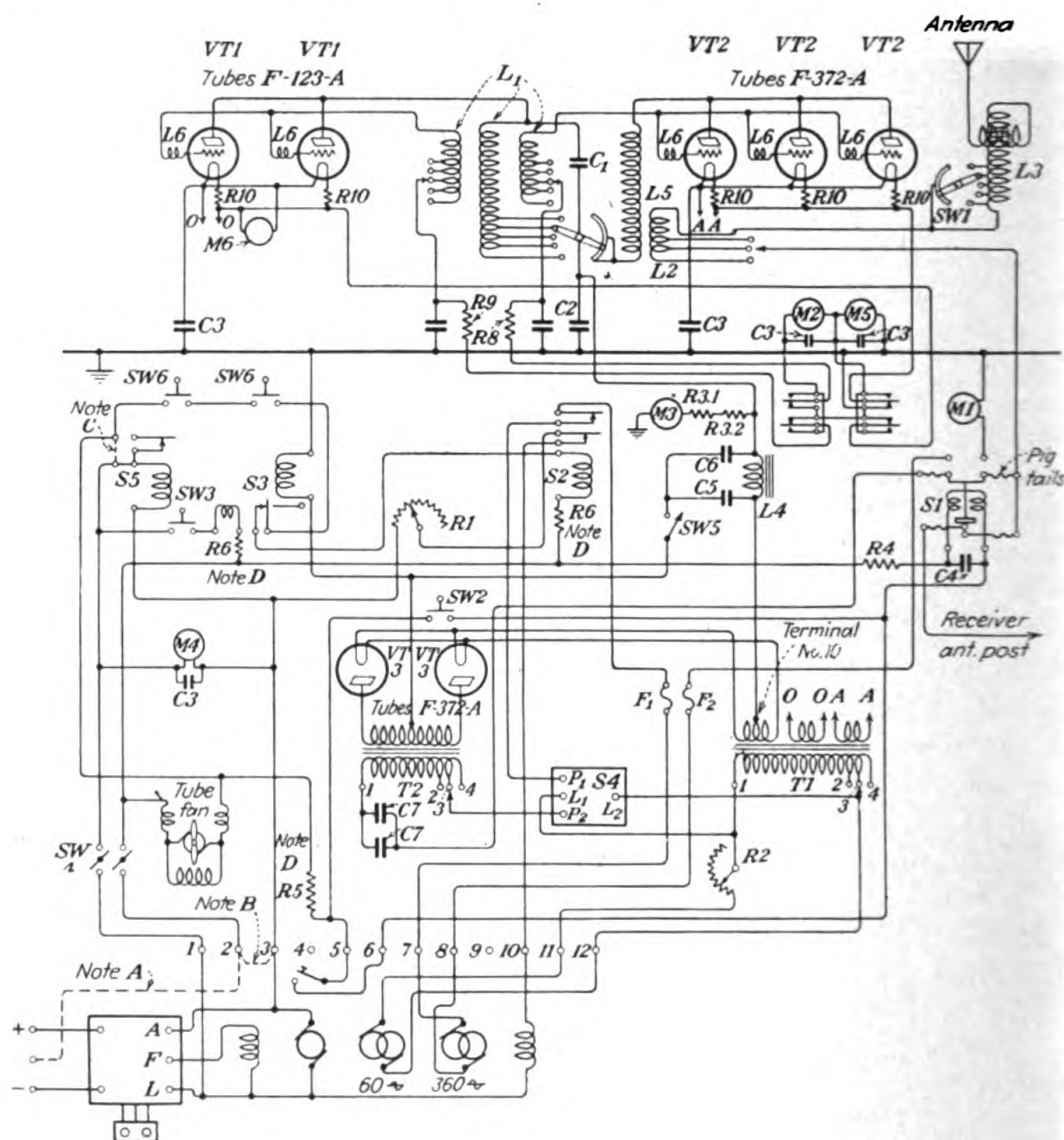
The radio transmitter may now be used as in normal service except that the plate voltage will be approximately 575 to 600 volts and the plate current approximately 0.23 amp. Although either A1 or A2 emission may be used, under distress conditions A2 would normally be employed. Since a lower value of antenna current is obtained under emergency operation from the 12-volt battery, the operator should take special care to resonate the antenna circuit carefully for maximum antenna current. Although the battery furnished with the equipment will provide 6 hr. operation as required by law, appreciably longer service may be obtained if the operator shuts down the dynamotor during extended listening periods. However, since approximately 15 sec. are required for the tubes to heat up, the dynamotor should not be shut down when it is necessary to reply quickly under distress conditions.

h. Care of Storage Battery.—Attention of operators is invited to the "Rules Governing Ship Service" of the FCC with respect to storage batteries, paragraphs 8.117 and 8.118. The charging arrangement provided on the emergency panel permits a normal charging rate of approximately $\frac{1}{2}$ amp. In general, the 12-volt battery may be left on continuous trickle charge, care being taken that the battery is not left on charge when the ship is in port or at other times when ship's power supply is not available, which might cause the battery to discharge through the supply lines. The CHARGE-DISCHARGE switch should be placed in the DISCHARGE position under such conditions, when no drain will take place from the battery as long as the START-STOP switch is in the STOP position. The voltmeter on the emergency panel will read only when the dynamotor is running.

2. MACKAY¹ SHIP RADIOTELEGRAPH TRANSMITTER² 109. *a. General Description.*—The 109 medium-frequency ship transmitter was designed to deliver 500 watts of modulated or unmodulated radio-frequency power to an efficient ship's antenna of the size usually available. It may be adjusted to operate at any five predetermined frequencies within the band 375 to 500 kilocycles or 800 to 600 meters wave length.

¹ Mackay Radio and Telegraph Co., Inc.

² All Mackay equipment is manufactured by the Federal Telegraph Co.



NOTES:

A - For 230-volt supply with neutral

B - For 115-volt supply or 230-volt supply if neutral is not available and transmitter is arranged for such condition

C - For 115-volt supply, or 230-volt supply without neutral omit *S*-5 and wire shown as dotted lines

D - For 230-volt supply without neutral only

FIG. 13-8.—Simplified schematic diagram of Mackay type 109 medium-frequency radio-telegraph transmitter.

PARTS FOR MACKAY SHIP RADIOTELEGRAPH TRANSMITTER TYPE 109 (Sec Fig. 13-8)

Symbol	Description	Symbol	Description
C_1	Oscillator tuning condenser, 0.005 mf.	$R_{1.1}$	Voltmeter multiplier.
C_2	By-pass condenser, 0.05 mf.	$R_{2.1}$	Voltmeter multiplier.
C_3	Meter by-pass condenser, 0.01 mf.	R_1	Key-relay resistor, 350 ohms.
C_4	Key relay condenser, 0.5 mf.	R_2	Auxiliary key-relay resistor, 500 ohms.
C_5	Filter condenser, 0.125 mf.	R_3	Auxiliary-relay resistor, 3,000 ohms.
C_6	Filter condenser, 1.0 mf.	R_7	Missing.
C_7	Power factor correction condenser, 8.0 mf., each.	R_8	Amplifier grid leak, 3,000 ohms.
F_1	Fuse, 360 cycles, 10 amp.	R_9	Oscillator grid leak, 5,000 ohms.
F_2	Fuse, 360 cycles, 10 amp.	R_{10}	Filament resistor, 5, each 0.25 ohm.
L_1	Oscillator coil (3 coils on a ceramic form).	S_1	Key relay.
L_2	Amplifier output transformer.	S_2	Protective relay.
L_3	Antenna load coil.	S_3	Overload relay.
L_4	Filter reactor, 4 henrys.	S_4	Filament-delay relay.
L_5	Plate coil.	S_5	Auxiliary relay.
L_6	Grid choke (one for each tube).	SW_1	Wave-change switch.
M_1	Antenna current meter, 15 amp., R.F.	SW_2	Test switch.
M_2	Grid current meter, 300 ma. D.C.	SW_3	Overload reset switch.
M_3	Plate voltmeter, 2500 volts, D.C.	SW_4	Control power switch.
M_4	Line voltmeter, 150 or 300 volts, D.C.	SW_5	Emission switch for shifting between A1 and A2 emission.
M_5	Plate current meter, 800 ma., D.C.	SW_6	Door switch.
M_6	Filament voltage, 15 volts, A.C.	T_1	Filament transformer.
R_1	Plate generator rheostat, 500 ohms for 115-volt line, 1,250 ohms for 230-volt line.	T_2	Rectifier plate transformer.
R_2	Filament rheostat, 3 ohms for 115 volt line, 12 ohms for 230-volt line.	VT_1	Oscillator tubes, F-123.
		VT_2	Amplifier tubes, F-372-A.
		VT_3	Rectifier tubes, F-372-A.

The transmitter consists of two separate frameworks securely bolted together one above the other. The upper contains the radio-frequency and control circuits, the lower the high-voltage rectifier and filament transformer. Interconnections are made with terminal blocks of corresponding numbers. A simplified schematic circuit diagram of this transmitter is shown in Fig. 13-8.

The power input for the transmitter is furnished from radio motor generator 107 which supplies 77 or 154 volts, 60 cycles, which is stepped down for filament excitation, and 250 volts, 360 cycles, which is stepped up, rectified, and filtered for plate supply.

The front panel of the transmitter carries all the indicating meters and the controls for wave change, tuning, filament and plate-voltage control, and A1 and A2 operation. Referring to the front view, a perforated metal door in the top center opens to allow access to the five type F-123 tubes mounted immediately behind it. The right-hand tube serves to amplify the output of the master oscillator tube on the left. A small removable panel just below the main panel covers a subpanel on which are mounted the fuses in the plate power supply and the keying, protective, and overload relays.

Doors to the lower section give access to the filament and plate transformers, rectifier, filter, blower, delay relay, and terminal boards. All external connections except the radio-frequency output and the receiver break-in leads are made at the terminal board near the base. The receiver break-in lead is taken from the proper terminal on the keying relay and

brought out the transmitter through the base section along with the power leads. This lead should be shielded to prevent pickup of strong noises and interference. Terminals 1 and 2 connect to the direct-current supply to energize the keying, protective, and line-voltage indicating circuits. Terminal 1 is negative, 2 is positive. The set supply switch, SW_4 on the diagram, opens the direct-current circuits for the protection of the operator when it is necessary to make adjustments inside the panel. Terminals 5 and 6 are connected to the keying circuit. It is not necessary to supply any external voltage since the keying relay is connected to the 110-volt supply.

Terminals 7 and 8 connect to the 360-cycle plate generator and furnish power to the rectifier transformer through fuses F_1 and F_2 , one contact of the protective relay S_2 , keying relay S_1 , and the rectifier-filament delay relay S_4 . The plate voltage is controlled by varying the field of the 360-cycle generator which is connected to terminal 10. The remaining contact of protective relay S_2 connects in series with the field control rheostat R_1 , so that the generator field is interrupted whenever the door switches or the overload relay are open.

Filament power supply for both the rectifier and the radio-frequency tubes is taken from slip rings on the motor through terminals 11 and 12. One transformer with tapped primary supplies through three secondary windings the oscillator tube, amplifier tube, and rectifier tubes. The filament rheostat controls the primary voltage of the transformer so that if the filament voltage of the oscillator filament as indicated by the filament voltmeter is correct, the voltage applied to all the tubes is correct.

The oscillator uses the conventional tuned-plate untuned-grid circuit with plate-voltage feed at the low end of the tank circuit so that no plate choke is required. Frequency variation is accomplished by moving taps along the tank inductance. Five leads are provided so that one of the preadjusted frequencies may be selected by moving the wave-change switch, which simultaneously changes the oscillator tank inductance, the primary inductance of the amplifier-coupling transformer, and the antenna inductance.

The amplifier input is inductively coupled to the oscillator tank through a tapped coil, wound alongside the oscillator grid coil, which allows adjustment of the excitation to suit loading conditions. The primary inductance of the coupling transformer of the amplifier plate is selected by changing taps on the coil through contacts on the wave-change switch. These taps have been set so that the amplifier tube has the maximum safe loading at the different assigned frequencies.

Power is transferred to the antenna circuit by the untuned plate-coupling transformer, the secondary of which is a part of the antenna circuit. The secondary tap to be used depends upon the antenna resistance.

The antenna loading coil is equipped with five adjustable taps which are set to tune the antenna approximately to resonance at each of the five operating frequencies. The variometer in the top section of the loading coil serves to resonate the antenna circuit. Considerable voltage is developed at various points on this coil at high antenna currents so that great care must be taken that the leads from the wave-change switch do not touch each other or any part of the coil to which they are not directly connected. The antenna-output lead is taken to the top of the set through a suitable lead-in insulator.

b Installation.—After installation, but before starting the set for the first time, a careful check of the wiring should be made to assure that the circuits are connected exactly as the wiring diagram shows in all respects. If the check is satisfactory, two type F-375-A mercury-vapor rectifier tubes and five F-123-A tubes may be inserted in their respective sockets. The plate connections to the oscillator and amplifier tubes should not be made at this time. The leads should be arranged, however, so as not to touch any part of the metal framework. Do not start the motor generator unless all the tubes are in place because too high a voltage may thus be applied to the filaments of those tubes which are already in place. Turn the filament and plate-generator rheostats to the right as far as they will go, and start the motor generator.

The filament voltmeter may be observed to determine when the motor is up to speed.

The filament voltage may then be raised to normal, 11 volts or slightly over. The rectifier filament voltage will be 5.1 when the voltmeter reads 11 volts. If a separate voltmeter is available, this may be checked. It is extremely important that the rectifier filament voltage be maintained slightly above 5 volts, because a lower voltage means a loss of emission from the filament which, in turn, causes bombardment of the filament, peeling, and eventual complete failure by hot spotting or filament burnout. The manufacturers recommend that the rectifier tubes be run at normal filament voltage without plate voltage at least 20 min. after being put in service for the first time, so that the mercury condensed on the filament and plate electrodes may evaporate and condense around the stem where it normally belongs.

In normal operation the filament-delay relay, located just over the rectifier tubes, will prevent the application of plate voltage to the rectifier for 30 sec. As a matter of extra precaution, however, the key should never be depressed until after this interval has elapsed so as to provide the necessary delay even if the filament-delay relay has become improperly adjusted. Applying plate voltage before the filament has attained proper temperature will greatly shorten the life of the tube. In some cases, life will end abruptly. Should the relay become inoperative for any reason and refuse to contact at all, the proper terminals, as determined from the circuit diagram, should be shorted. *In this case, extra precaution must be exercised that the interval of 30 sec. is observed.*

After the 20-min. delay mentioned above, the signaling key may be closed and, if all the door switches and the overload relay are closed, and the line fuses intact, voltage will be applied to the rectifier-tube plates and the plate voltmeter will indicate. The oscillator-tube plate lead should then be connected, after making sure that all voltage is removed from the set. With the meter switch turned to the left to read oscillator grid and plate currents, the key is depressed and both meters should show current flowing. With the switch turned to the right to read amplifier currents, the grid meter should swing relatively high. The frequency of oscillations should be that marked on the wave change switch tap in use. If a frequency other than that marked

is desired, the left-hand side screen, middle section, must be removed to give access to the oscillator coil tap which is to be changed.

Caution: Special care should be taken to remove all supply voltage when the side screens are removed as no automatic protection is then available.

The oscillator coil is the copper-strip coil in the lower section and is surrounded by a narrow section of Bakelite tubing on which the oscillator and amplifier grid coils are wound side by side. Two or three trials should locate the exact position of the tap to give the required frequency. The side screen must be replaced for each trial, however, since the frequency is changed when the screen is not tightly screwed to the frame. Do not attempt to adjust the grid excitation of either the oscillator or amplifier until operating conditions are approached unless, of course, the oscillator refuses to operate otherwise.

When the oscillator is adjusted to the desired operating frequencies, the amplifier plate lead should be connected and the antenna circuit resonated. The entire 20-turn secondary coil of the amplifier plate-coupling transformer should be used at start. This transformer is located behind the amplifier tube on the right side of the top shelf and may be reached by taking off the upper-right-hand screen. The inner coil is the primary and the outer coil the secondary. In case the right side of the set is inaccessible, the tubes must be removed so the coil may be reached through the front door. By removing the top screen on the left side of the frame, access may be had to the antenna loading coil. The five clips from this coil which are connected to the wave-change switch should each be placed in its proper position on the loading coil so that at each frequency the antenna circuit may be resonated at a convenient position on the antenna variometer. In the laboratory test of this transmitter, the antenna loading coil was tapped correctly for an antenna capacity of 0.001 mf.

Returning to the amplifier plate-coupling transformer, the inner or primary coil has been designed to resonate over the entire operating band. The outer coil has a single flexible lead which should be placed on the tap on the outer coil which provides the desired full load amplifier plate current. When connected to the correct tap, the plate voltage adjusted to 2,000, A1 operation, and the antenna resonated, the amplifier plate current should be slightly *under* 500 ma. at 500 kilocycles and slightly *over* 500 ma. at 375 kilocycles. Operation on A2 emission should be approximately the same for the same plate voltage. In no case should the plate voltage be allowed to exceed 2,000 volts.

Finally, the grid excitation of the oscillator and amplifier tubes should be checked for operation within the following ranges: for the oscillator, 50 to 100 ma.; for the amplifier, 75 to 150 ma. Adjustment is accomplished by moving the taps on the grid-coupling coils surrounding the oscillator plate-tank coil. The oscillator grid taps are those on the left; amplifier on the right. Excitation is increased by selecting a lower tap. The oscillator grid current will remain practically constant with frequency changes within the operating range, but the amplifier grid current usually increases with frequency. The total variation, however, should be held within the above limits.

An accompanying data sheet serves as a basis of comparison for correct operation. The tests recorded were made for maximum output, and the respective currents given should not be exceeded for continuous operation.

If adjustments are all satisfactorily made, the transmitter will be ready for regular service.

c. Normal Operating Procedure.

1. See that the motor-generator switches are thrown to supply voltage to the transmitter.

2. Press the start button at the operating position. The filament voltage should immediately start to rise. Adjust the filament voltage to slightly over 11 volts. Note that when power is being drawn from the motor generator the line voltage, and thus the filament voltage, is likely to drop. It should not be allowed to drop below 11 volts.

3. Select the desired operating frequency on the wave-change switch on the lower right side of the front panel.

4. Ascertain that 30 sec. has elapsed since the tube filaments were lighted, depress key, and tune the antenna circuit to resonance by tuning the variometer dial on the top center of the front panel. Use maximum antenna current as indicated on data sheet.

5. If A2 operation is desired, turn the proper switch to A2 position. Be sure that the key is not depressed when A1-A2 change-over is made.

6. The set is now ready for operation.

7. To shut down, press the stop button.

d. Emergency Operation.—In case the rectifier tubes go bad and no spares are available, emergency A2 operation at reduced power may be had by removing both rectifier tubes from their sockets, disconnecting one rectifier plate lead from the plate transformer, and connecting the other plate lead to terminal 10 on the filament transformer. Terminal 10 is the center terminal of the only group of three terminals on the transformer behind and above the plate transformer. The A1-A2 switch must be thrown to A2 (ICW) position.

The operator should acquaint himself with this procedure, so that in an emergency no trouble will be experienced in making the change-over.

Should one or more F-123-A tubes fail and replacements be not immediately obtainable, operation may be conducted with one F-123-A tube in an oscillator socket and two F-123-A tubes in two of the amplifier sockets. Under these conditions, the plate voltage must not be allowed to exceed 1,500 volts. Approximately 50 per cent of the normal power output will be obtained.

13.5. Emergency Transmitter. MACKAY TYPE 131-A. *a. Description.*—All ships required by law to carry radio equipment are required to have as part of their radio-transmitting installation an emergency transmitter with a normal range of 100 miles using modulated continuous waves. On cargo vessels, the main transmitter may be designed for this emergency operation, but on passenger ships a separate and distinct transmitter is required. The Mackay type 131-A transmitter is designed for this purpose. A circuit diagram is shown in Fig. 13-9.

This set is designed to generate an 800-cycle A2 wave in the 600- to 800-meter band with an output of 50 watts into the antenna. Power for the motor generator of this transmitter is secured from a 12-volt storage battery. No provision is made for any other source of power.

The motor generator delivers 110 volts at 800 cycles which is applied directly to the plates through a step-up transformer.

The filaments are lighted directly from the 12-volt battery, proper filament voltage being secured by an adjustable resistor in series with the filament line. The battery is charged through a separate battery-charging resistance unit, mounted separately and known as battery charger 104A. (See Fig. 14-12.)

This transmitter employs four type 10 tubes connected in push-pull pairs and arranged in a conventional tuned-plate, untuned-grid inductive

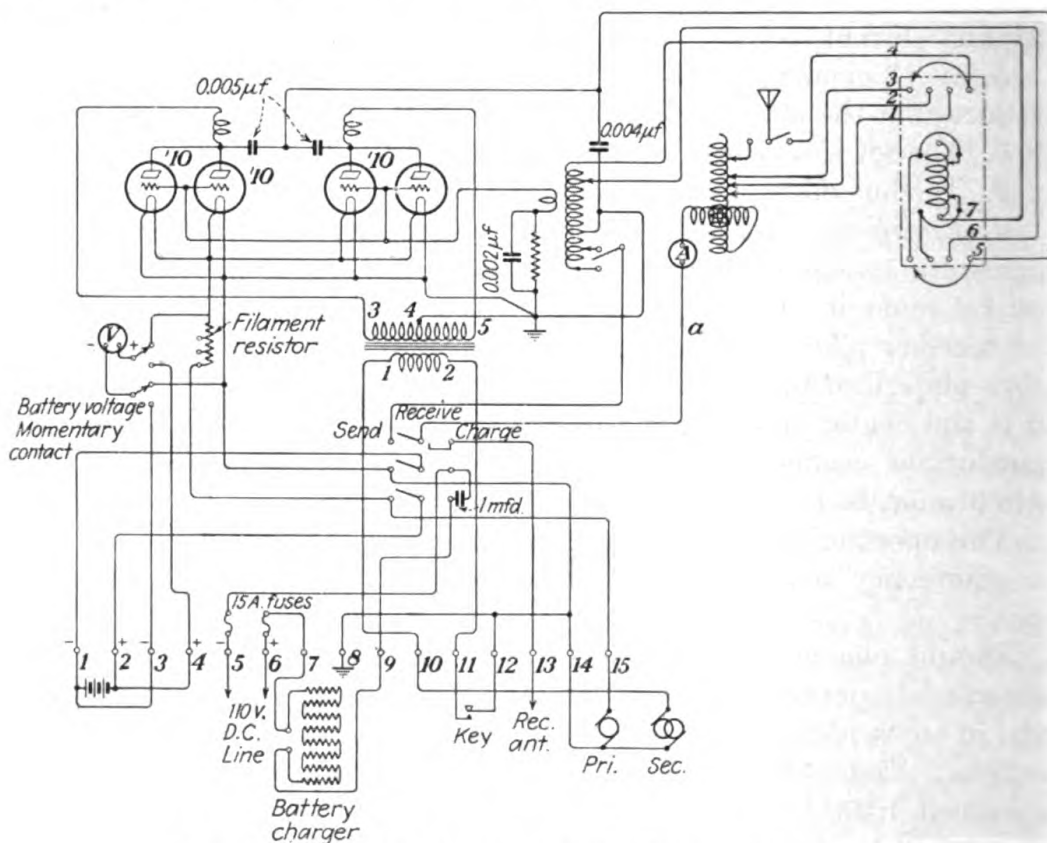


FIG. 13-9.—Mackay type 131-A radiotelegraph transmitter.

feed-back (Armstrong) oscillator circuit, with raw alternating-current plate power.

The antenna circuit consists of the ship's main antenna or a special antenna erected for use in emergencies, a loading coil provided with taps for coarse adjustment, and a variometer rotor for fine adjustment of the antenna circuit to resonance. Two antenna terminals are provided, one for use on the main antenna and one for use with the emergency antenna. A movable link is provided to switch from one antenna to the other.

The frequency is determined by a closed circuit in the plate circuit, which is adjustable by means of a clip on the inductance and a rotating half turn so arranged that the frequency may be set at any desired degree

of precision by the variometer effect between the half turn and the rest of the coil.

The antenna is coupled to the oscillating circuit inductively with the necessary clips to provide adjustment when the ship's main antenna or the emergency antenna is used.

Meters are provided to read antenna current and filament voltage. The voltmeter has a two-way toggle switch so that the meter may be switched to read filament voltage or battery voltage.

Keying is accomplished by breaking the power supply to the plate-transformer primary with the hand key as shown in the schematic diagram.

The operation of this transmitter is controlled by a three-position switch mounted on the front panel. This switch when in the **SEND** position starts the motor generator and connects the antenna to the transmitter. In the **RECEIVE** position this switch stops the motor generator and connects the antenna to the receiver. In the **CHARGE** position the battery is placed on charge while the antenna is left connected to the receiver.

This transmitter is tuned and made ready for operation by the installation engineer from directions supplied in the instructions booklet supplied with the transmitter by the manufacturer. There is no point in repeating them here as the operation is the same as for any tuned-plate, untuned-grid inductive feed-back transmitter. A precision frequency meter must be available for this tuning procedure.

b. Operating Instructions.—To place the transmitter in operation, check to see that the proper antenna is connected to the transmitter. Then throw the control switch to the **SEND** position, and operate the key. Throwing the switch to the **RECEIVE** position stops the motor generator and connects the antenna to the receiver. When the transmitter is not in use, the control switch should be kept in the **CHARGE** position. This charges the storage battery at a 5-amp. rate, leaving the antenna connected to the receiver so that the operator can listen in while the battery is on charge.

With a fully charged battery, the filament voltage should read 8.5 volts under full-load operating conditions. A tapped filament resistor is mounted on a base at the right of the antenna load coil. The tap on this resistor which gives the nearest reading to 8.5 volts should be selected. This reading should be taken of the battery when fully charged and operating under full-load conditions.

A weekly check should be made of the specific gravity of the storage-battery electrolyte which should be kept at a value of 1.275. Distilled water should be added to the battery at least every two weeks so that the level of the electrolyte will be kept well above the plates. The operator should ascertain that his battery is fully charged at all times.

Care must be taken, however not to overcharge the battery as this shorten its life.

In the absence of a hydrometer, a fairly good check on the battery condition may be obtained by the use of the voltmeter. Read the battery voltage with the control switch in the RECEIVE position. Then throw the switch to the SEND position and close the key. Again read the battery voltage under full-load conditions. The difference between these two readings compared with similar readings taken when the battery is known to be fully charged will provide a fairly good indication of the condition of the battery being tested.



FIG. 13-10.—Radio-equipped motor lifeboat.
(Courtesy of R.M.C.A.)

This transmitter is small in size, and provisions may be made for mounting it directly on the bulkhead of the radio room.

13.6. Lifeboat Radio Equipment.—International regulations require passenger vessels to install radiotelegraph equipment in one motor lifeboat when the total number of lifeboats exceeds 13. Two such installations are required when the total number of lifeboats exceeds 19.

1. R.M.C.A. MODEL EJ-8007. *a. Description.*—The equipment about to be described is designed especially for installation in lifeboats. Important in this equipment are the following parts:

One ET-8007 combined radio transmitter and receiver in a weatherproof case.
One 12-volt storage battery consisting of six cells of MVA-11 Exide battery in two trays to give a rating of 12 volts, 162 amp.-hr., at the 6-hr. rate.
One lead-lined battery box with ventilating cover for the 12-volt battery.
One 50-ft. length of $\frac{1}{8}$ in. tinned copper wire for the lifeboat antenna.
Two 12 in. Bakelite antenna insulators, $\frac{3}{4}$ in. diameter.
One pair headphones Trimm No. F-100, 3,000 ohms. (Headphones are stored in cabinet cover. Telegraph key is built in transmitter and projects through panel.)
One box of spare parts.

b. Antenna and Ground.—The scheme of antenna installation is shown in Fig. 13-10. The actual length of the antenna, of course, varies with the lifeboat in use. Usually the flat top is about 20 ft. long and the lead-in about 20 ft., the total antenna length being about 40 ft. The operator and equipment are somewhat protected from the elements by a steel housing which serves as a radio shack.

The main radio ground for the transmitter is made through the — 12-volt circuit on the set side of the double-pole single-throw battery switch. The — 12-volt lead into the set from the switch is grounded to the switch box. The main radio ground is then made from the switch box to the hull of the lifeboat in the case of metal lifeboats. On wooden boats, a ground connection should be run to the engine base and propeller shaft and also to a copper plate (not painted) on the hull below the water line. This plate should have an area of at least 6 sq. ft. Ground connections on wooden boats should also be made to the metal keel strip and to the metal canopy which houses the entire radio installation.

c. The Transmitter.—Two type 10 tubes are used in a full-wave self-rectified Colpitts oscillator circuit designed solely for the distress frequency, 500 kilocycles. A schematic diagram of the circuit is shown in Fig. 13-11. The complete unit as installed is shown in Fig. 13-12. The input to the plate circuit of the oscillator tubes is approximately 85 watts. Plate supply is obtained through a step-up transformer from a 110-volt 500-cycle output dynamotor. This dynamotor operates from the 12-volt storage battery and is mounted inside the transmitter cabinet. The transmitter is adjusted to 500 kilocycles by means of a small rotor at one end of the tank inductance. This rotor is adjusted by removing the name plate on the panel marked FREQUENCY, which exposes an adjusting screw. A screw driver is then used to turn the rotor for the 500-kilocycle adjustment. A ratchet wheel on the rotor shaft maintains the setting. Antenna coupling is adjusted in a similar manner by removing the antenna coupling name plate. After both of these adjustments have been properly made, the name plate is replaced, thereby covering the controls and preventing tampering.

d. The antenna circuit, which requires considerable loading on account of the very small antenna which must be used (see Fig. 13-10), is provided with a loading coil containing a variometer and six taps on the stator winding. On initial installation, the correct antenna tap must be deter-

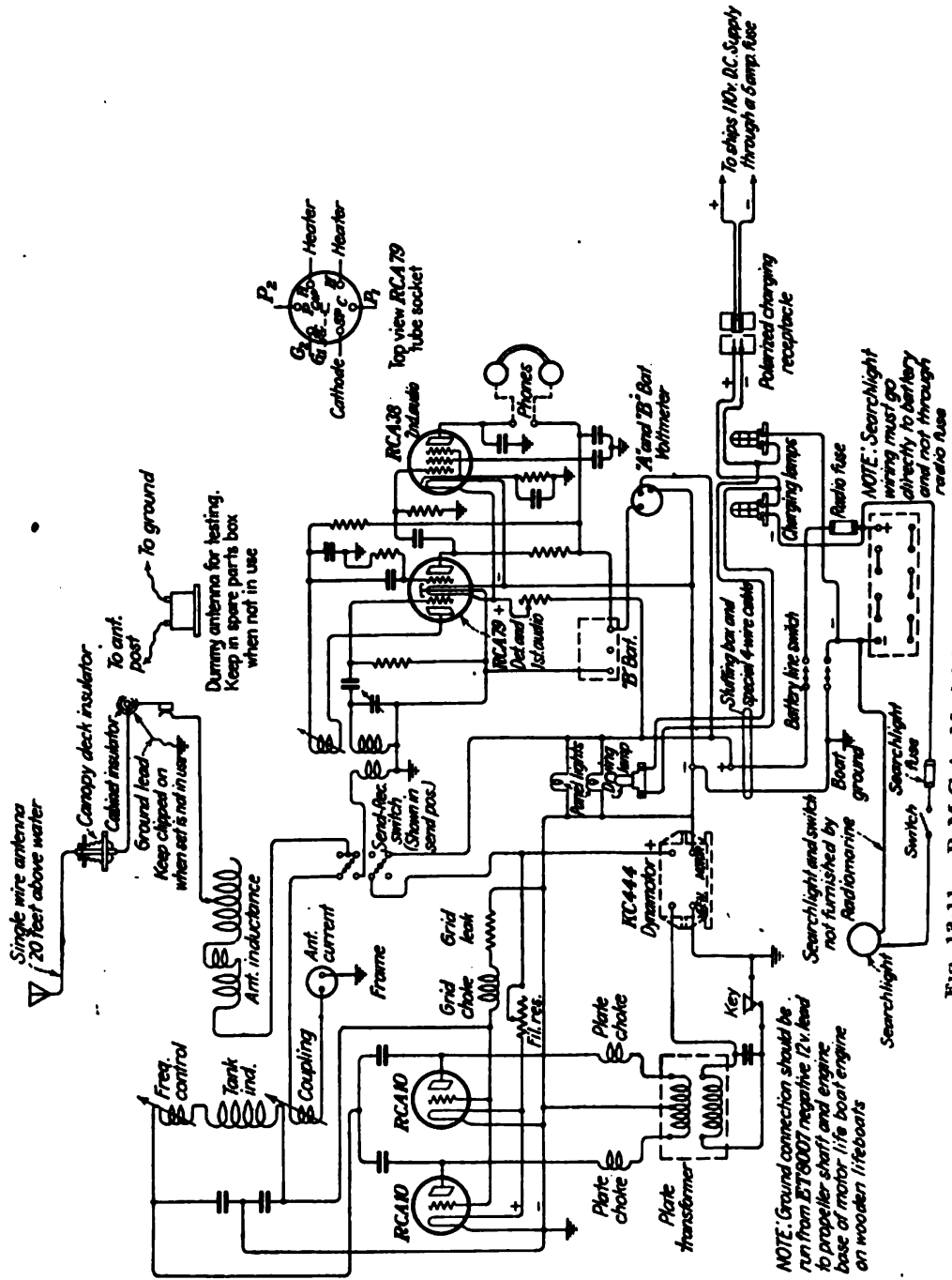


FIG. 13-11.—R.M.C.A. Model E.J.-8007 lifeboat radio equipment.

ed by trial, that tap being selected which resonates 500 kilocycles in the variometer pointer as near as possible to the middle of its scale.

e. The radio receiver uses a twin triode type 79, of which one-half is used as a regenerative detector and the other half as the first-stage audio amplifier. The second tube in the receiver is a type 38 pentode and acts as the second-stage audio amplifier. The receiver covers a range of 350 to 550 kilocycles. The receiver may be used for A1 signals by increasing the coupling of the tickler coil, which is adjustable with respect to the detector grid coil. Plate supply for the receiver is obtained

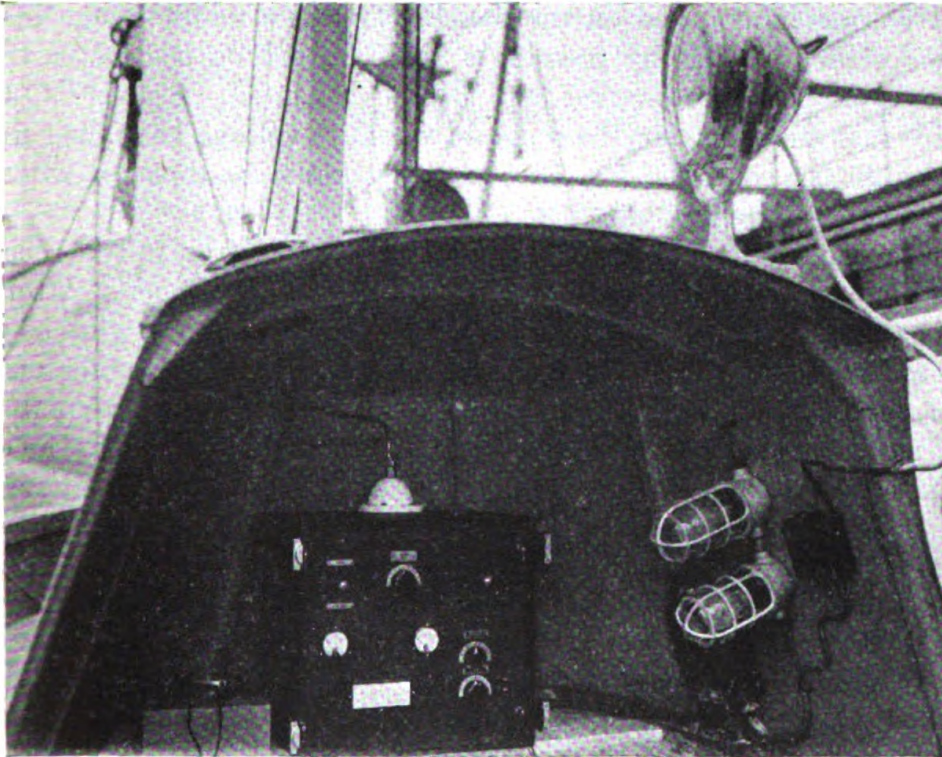


Fig. 13-12.—R.M.C.A. Model EJ-8007 lifeboat radio equipment as installed. (Courtesy of R.M.C.A.)

from a 45-volt Burgess No. 5308 *B* battery, which is clamped inside the binet assembly. Filament supply for the receiving tubes is taken from a 12-volt storage battery through a suitable resistance which is adjusted at the factory to apply 6 volts to the receiver filaments or heaters.

Transmitter filaments are energized from the 12-volt battery through a 3-ohm resistor which is adjusted at the factory to apply 7.5 volts to the type 10 tube filaments.

A send-receive switch on the panel transfers the antenna circuit either to the coupling coil of the transmitter or the coupling coil of the receiver, and also in the transmit position closes the 12-volt circuit to the dynamotor input and to the type 10 tube transmitter filaments. The receiver filaments, however, are energized as soon as the external battery switch

is closed. Also when this switch is closed, 12 volts is applied to the two panel lights on the transmitter-receiver panel.

In order to keep the inside of the equipment free from moisture, a 25-watt 110-volt light is mounted inside the assembly and is connected through the outgoing power cable to the 110-volt charging-line circuit. This lamp should burn at all times when the lifeboat is on the davits. To avoid excessive temperature rise inside the cabinet, no lamp larger than 25 watts should be used.

Antenna current is read by means of a 2-amp. radio-frequency instrument. Battery voltage from the 12-volt storage battery is read from a small voltmeter mounted on the panel. This is a double-range instrument designed so that by pressing a small button on the meter the *B* battery voltage of the receiver may also be measured. Since FCC rules require that the *B* battery be replaced when its voltage has fallen under load by 20 per cent, the No. 5308 battery should be replaced when its voltage is less than 36 volts.

In order to permit easy withdrawal of the transmitter-receiver assembly, a pair of rollers is fitted in the base of the cabinet. After the main cabinet cover has been removed, turn the four panel latches so that they are in a vertical position. Then by means of the handles on the panel carefully withdraw the assembly. The four-conductor cable is made sufficiently long so that the assembly may be pulled out to the edge of the cabinet. For major repairs, the cable should be disconnected from the transmitter-receiver unit. However, to replace a *B* battery or tubes, it is only necessary to withdraw the assembly about halfway. When replacing the unit in the cabinet, make sure that the four-conductor cable does not get fouled in the rear.

f. General Maintenance and Operation.—When the equipment is first installed, the masts and antenna should be erected and a temporary ground connection made to the hull of the ship while the lifeboat is resting on the davits. The correct antenna-load coil tap may then be selected and the coupling and frequency adjustments made. When the lifeboat is in the water, it will be found that these adjustments will hold with possibly a slight change in the setting of the antenna variometer.

For routine testing as required by FCC rule, a small dummy antenna is furnished. This unit should be kept in the spare-parts box when not in use.

Regulations require that the lifeboat equipment be tested "within 24 hours prior to departure to sea from any port and at least once each year with the lifeboat afloat in the water." The results of the inspection and tests should be noted in the ship's radio station log, and the master informed. For this test and inspection when the lifeboat is not in the water, the dummy antenna may be used.

Operators should follow the test procedure outlined below:

1. Inspect antenna, antenna insulators, and main canopy insulator to see that they are in good condition and available for immediate use.
2. Examine both charging lamps to insure that the battery is being charged.
3. Remove main cover from cabinet.
4. Temporarily disconnect lead from cabinet antenna post to canopy deck insulator and connect dummy antenna between ground and antenna post on transmitter. A wing nut is provided on transmitter antenna post to facilitate this operation.
5. Close battery switch which should cause panel lights to be turned on. The panel SEND-RECEIVE switch should be in the RECEIVE position. After about 30 sec. required for the receiver tubes to heat up, the receiver may be checked by listening in the phones and by turning the tickler coil to maximum regeneration. The usual tube noise should be observed, and possibly strong near-by signals may be picked up by the dummy antenna. After the receiver has been operating a few minutes, press the voltmeter button and determine that the *B* battery is not less than 36 volts. If it is, a new *B* battery is required.
6. The panel SEND-RECEIVE switch should now be placed in the SEND position, which will start the dynamotor and close the transmitter filaments. The key should then be closed and the antenna variometer rotated until maximum antenna current is obtained. Hold the key closed for about 5 min. (not in silent period), and observe that the battery voltage does not drop appreciably under load.
7. If these tests indicate that transmitter and receiver operation appear normal, the transmitter switch should be left in the RECEIVE position and the battery switch turned off. The antenna variometer should be retuned to its original position as determined by initial tests on the actual antenna. The dummy antenna should be disconnected, returned to the spare-parts box, and the main antenna lead firmly connected to the transmitter antenna post.
8. The main cabinet cover should then be placed back in position, taking care that the four cover latches are drawn tightly. This is important to insure that dampness will not get inside the set.
9. Once each 60 days the operator should partly withdraw the assembly from the cabinet and inspect the 25-watt "drying" lamp to see that it is burning. Once each 6 months the steel rollers at the bottom of the cabinet should be well greased to prevent sticking.

g. Battery Maintenance.—FCC rules require that once each 7 days the operator shall inspect all batteries, and in the case of storage batteries, log the condition and gravity of the battery. In the case of the dry battery, Burgess No. 5308, this should be replaced when it falls below 36 volts, as previously explained.

The MVA-11 12-volt battery with this equipment is arranged for continuous trickle charge. The correct charging rate is determined to a certain extent by the time of year and whether or not a ship is in tropical latitudes a considerable part of the time. In hot weather or in tropical latitudes, a charging current of 500 ma. will keep the battery in first-class condition. This is obtained when two 100-watt 110-volt tungsten-filament lamps are used in the charging-lamp receptacles. For ships in more northerly waters and in the wintertime, a lower charging rate is desirable. This may be obtained by using two 75-watt 110-volt tungsten-filament

lamps, which will provide a charging rate of 400 ma. Once each 7 days, the operator should measure and log the specific gravity of the battery and determine that it does not fall below approximately 1.250. If it is found that the battery requires excessive water, indicating overcharge, then smaller sized lamps should be used. If two or more successive battery readings indicate low specific gravity, then larger charging lamps should be used. In general, 75-watt lamps will be found satisfactory and will provide sufficient charge to overcome the internal losses of the battery as well as the small power drawn from the battery when the equipment is being tested. Operators are cautioned to watch the conditions of the battery, using approved water to keep the electrolyte level above the plates, and to make sure the charging plugs and receptacles are in circuit at all times and that the polarity of the charging circuit is not accidentally reversed by ship's personnel. In case the ship's power supply fails for short periods of time, the battery will not be adversely affected since the leakage current back through the line is limited to a fraction of an ampere by the charging lamps. Remove charging plug when ship is in dry dock.

It will be noted from the diagrams that one charging lamp is used in series with each side of the line. This is to prevent short circuits or damage to the equipment or lines in case one side of the ship's supply should be grounded at the same time that the negative 12-volt battery is grounded through the battery switch. For example, if negative ship's line is grounded and the battery switch is closed, the result of placing a ground on -12 volts will be to extinguish one of the charging lamps and cause the other to burn brighter.

h. Test for Battery Rating.—When FCC inspectors test the equipment to determine if the battery rating is adequate, the following procedure is used. The maximum current drawn from the battery by the transmitter-receiver unit with the key closed is determined. In the case of the ET-8007 equipment, this current will be approximately 22 amp. The searchlight load is then measured and in the case of an 80-watt 12-volt searchlight, will be 6.5 amp. The battery is then discharged at 70 per cent of the transmitter-receiver key-locked load, which will be 15.4 amp. During this discharge, the searchlight is turned on for the first 30 min. of each hour of the 6 hr. A calculation will then show that the transmitter has required approximately 92.5 amp.-hr. and the searchlight about 20 amp.-hr., or a total of 112.5 amp.-hr. Since the battery is rated as 162 amp.-hr., it is evident that considerable additional capacity is available before the voltage per cell at the battery falls below the permissible value of 1.8 volts.

i. Precautions.—The following rules must be observed:

1. Keep the ground lead connected to the antenna post when the set is not in use.
2. Never test the lifeboat set on the deck with its operating antenna while the ship's main transmitter is in operation as the lifeboat's receiver may thus be burned out.

3. When the lifeboat equipment is tested in water, and away from the strong field the ship's antenna, Rule 2 does not apply.

4. When the lifeboat transmitter is tuned to 500 kilocycles by inspectors, and when antenna-coupling adjustment is made, always make certain that the ship's main antenna is open. Otherwise, the ship's main antenna may cause erratic operation by absorbing power from the lifeboat antenna.

2. MACKAY TYPE 101-A. *a. Description.*—This lifeboat radio equipment is intended to provide communication between the lifeboat and a rescue vessel, or between two lifeboats similarly radio equipped. The transmitted signal is of the modulated, or A2, type, the tone frequency being 1,600 cycles. Satisfactory radiotelegraphic communication may be expected between lifeboat and rescue vessel over distances of at least

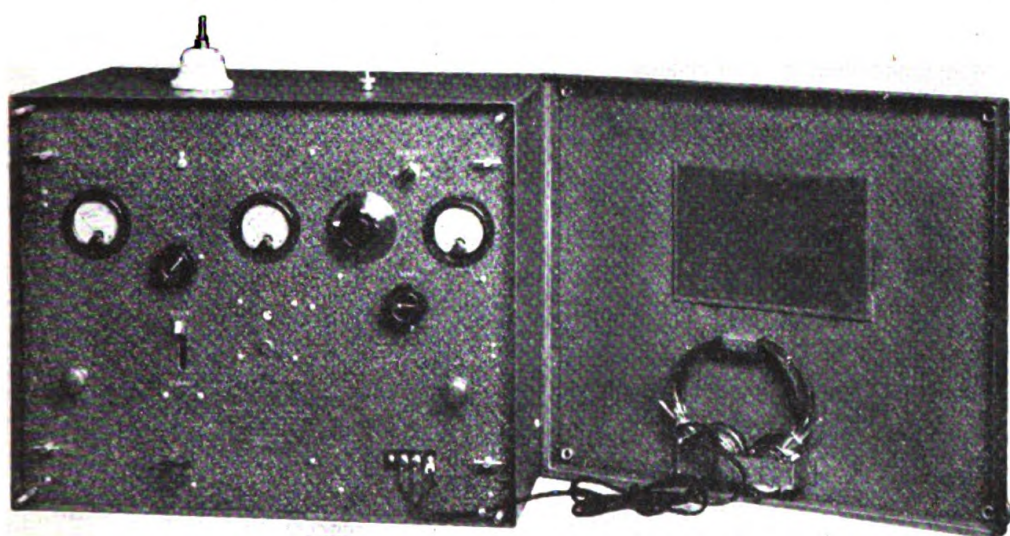


FIG. 13-13.—Mackay Type 101-A lifeboat radio equipment. (Courtesy of Mackay Radio and Telegraph Co., Inc.)

10 nautical miles over water when operated with a single-wire antenna not less than 20 ft. above the water line. The equipment consists of a box-like unit containing a transmitter, receiver, headphones, and motor alternator. In addition, there is supplied a storage battery and a battery charger and a spare-parts box containing spare tubes of each type, pliers, screw driver, wrench, sandpaper, spare brushes, antenna condenser, spare antenna wire with insulators, and an instruction book. The unit is shown in Fig. 13-13.

b. Transmitter.—This transmitter is designed to operate at a frequency of 500 kilocycles into antennas of capacities ranging from 30 to 20 mmf. Tuning is accomplished by means of a small variometer control on the panel. Adjusting the tuning control for maximum brilliancy of the resonance-inductor lamp sets the frequency at 500 kilocycles. A small knurled cover may be removed and the resonance indicator adjusted to 500 kilocycles with reference to a standard wave-

meter by means of a screw driver at the time of installation. A loop of wire at the right end of the oscillator coil provides the coupling to the resonance indicator. This may be positioned to give suitable brilliancy of the indicator lamp at installation.

Too much emphasis cannot be laid upon the importance of careful antenna insulation, because the antenna voltages become very high owing to the type of circuit necessarily employed to feed an antenna of small dimensions. Poor antenna insulation places a load directly across the oscillating circuit, requiring increased grid excitation and reducing the output of the transmitter.

The transmitter, receiver, and motor alternator are mounted on a substantial metal chassis which is housed in a metal cabinet. All controls for operation, meters, and key are provided on the face of the chassis. For protection when not in use, a watertight cover is clamped in place.

The transmitter employs four type 10 transmitting tubes.

Taps are provided on the grid and plate coils to permit adjustment for maximum antenna current at installation. The binding posts for the grid taps are at the top right end of the coil, and the binding posts for the plate taps are at the left end of the coil. These may need readjustment in case an emergency antenna of some sort is rigged.

A tapped filament resistor is provided in the left rear corner of the chassis. If the filament voltage under load at installation, with the key closed and a fully charged storage battery, is not at least 8.2 volts, the tap on this filament resistor may be changed.

c. Operation.—The operation of the transmitter is quite simple. It is necessary only to throw the transfer switch to the TRANSMIT position and proceed with keying. The key and switch controls protrude from the front of the set. When transmission is complete, the switch is thrown to the RECEIVE position. This action automatically shuts down the transmitter and transfers the antenna to the receiver.

The filaments of the transmitting tubes are lighted from the storage battery. Normal filament voltage is about 8.2 volts on a freshly charged storage battery, which will gradually drop as the battery is discharged. The transmitter will remain in operation, however, until this voltage has dropped to 6 volts or less. The plate voltage is secured through the associated motor alternator which converts the 12 volts direct current to 110 volts, 800 cycles, alternating current. The step-up transformer is mounted within the transmitter and delivers 600 volts, 800 cycles to the tube plates.

A simplified schematic diagram of this equipment is given in Fig. 13-14.

d. Receiver.—The receiver is located at the upper right-hand corner of the cabinet and is designed to cover a frequency range of 300 to 550 kilocycles. Two type 6D6 and one type 41 tubes are used to provide

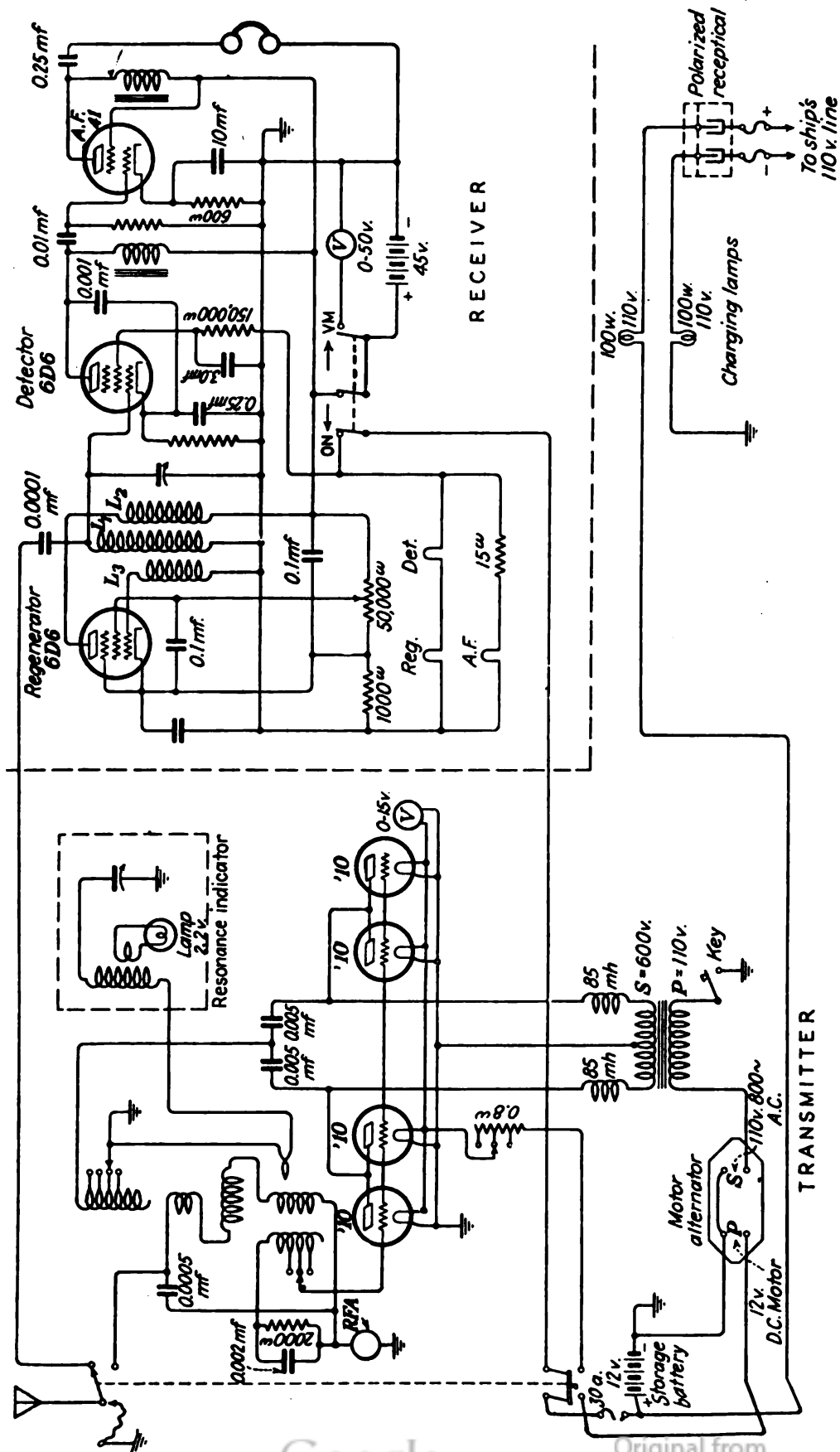


Fig. 13-14.—Mackay Type 101-A lifeboat radio equipment.

a regenerative detector and one stage of audio-frequency amplification. There are provided on the front panel a tuning dial, a regeneration control, a battery switch, and a plate voltmeter. The plate supply is furnished by one 45-volt *B* battery mounted behind the receiver chassis. The filament supply is obtained from the 12-volt storage battery by a series parallel connection of tube heaters. Headphones are attached to a screw-terminal board below the receiver controls.

To operate the receiver, move the switch at the left center of the panel up to the *RECEIVE* position, turn the battery switch located near the upper right corner to the right to the position marked *ON*. Allow about one-half minute for the tubes to heat up. Advance the regeneration control to the right until the receiver goes into oscillation as indicated by the click in the headphones. Operate the receiver in the vicinity of this point, just oscillating for *A1* signals, and either just oscillating or just under the oscillating point for *A2* signals. With the regeneration control so set, slowly adjust the tuning dial, located to the left of the plate voltmeter, until a signal is picked up. Signals on 500 kilocycles (600 meters) will be picked up when the pointer is about one-third away from the left-hand limit. Lower frequencies or longer wave lengths will be tuned in by turning the tuning control further to the right. The receiver need not be turned off during periods of transmission.

e. Testing.—When testing with the lifeboat afloat, the masts should be erected and the equipment operated into the real antenna. The transmitter should show normal antenna current and be on 500 kilocycles when the tuning is adjusted to show maximum brilliancy of the indicator lamp. The filament voltmeter should read at least 8 volts with the key closed. The receiver should show normal operation and good reception from ship and shore stations within 50 to 100 nautical miles.

The *B* battery voltage of the receiver can be determined by turning the battery switch to the left to the position marked *VM*. If the voltage is less than 42 volts when the meter is first turned on, the battery should be replaced. A better procedure would be to check the voltage before and after a 10-min. period of operation of the receiver. A defective battery will show a drop of at least 2 or 3 volts during this period. The drain on the battery by the voltmeter is about the same as that by the receiver, so the switch should always be turned to its *OFF* position after test. When testing the transmitter with the lifeboat in the davits, the dummy antenna condenser is used. The real antenna must be disconnected, and the dummy-antenna condenser placed on top of the transmitter case, with one spade terminal of its base under the screw provided for it on the transmitter case, and the flexible lead from the top of the condenser connected to the antenna insulator on the top of the transmitter. With the key closed and the tuning adjusted to maximum

brilliancy of the resonance-indicator lamp, the antenna current should be 1 amp. or more and the frequency 500 kilocycles. The filament voltmeter should read at least 8 volts with the key closed. The receiver should also indicate normal operation.

Reception may be checked by attaching a 20-ft. piece of wire to the antenna post in place of the regular antenna or the dummy. This wire should be thrown free of the metal structure of the ship.

The storage battery should be tested with a hydrometer. Its specific gravity when fully charged is 1.280; when completely discharged, it is 1.150.

13.7. High-frequency Radiotelegraph Transmitters.—For long-distance communication, marine radio depends on the high-frequency radiotelegraph transmitter. In fact, constant communication with ships in all parts of the world can be maintained through a coast station located on either the east or west coast of the United States. It is the purpose of this section to discuss this type of transmitter in detail.

1. R.M.C.A. MODEL ET-8019 RADIO TELEGRAPH TRANSMITTER.

a. General Description.—This transmitter, a photograph of which is shown in Fig. 13-15, is designed primarily for marine applications and provides a number of important operating characteristics not heretofore available. For example, in the design of this transmitter full advantage is taken of the efficiency of modern beam vacuum tubes, together with simplified controls, small space requirements, as well as coverage of all assigned high-frequency bands for ship radiotelegraph service.

b. Frequency Range.—This transmitter is designed to cover eight frequency bands between 4,140 and 22,140 kilocycles. These bands include all frequencies allocated by the FCC to ship radiotelegraph service in the 5.5 to 17-megacycle and 4- to 22-megacycle bands. The frequency coverage of these bands in kilocycles is as follows:

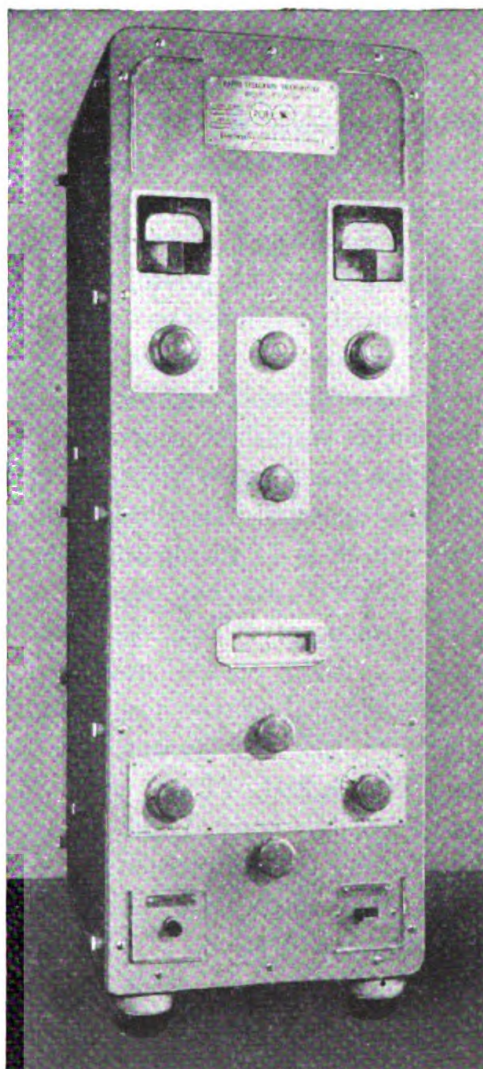


FIG. 13-15.—R.M.C.A. Model ET-8019 high-frequency radiotelegraph transmitter. (Courtesy of R.M.C.A.)

4,140-4,165	11,020-11,070
5,510-5,535	12,360-12,480
6,210-6,240	16,480-16,660
8,240-8,330	22,025-22,140

c. Antenna Power.—This transmitter is designed to deliver 200 watts or more to the antenna in the frequency bands between 4,140 and 16,660 kilocycles. In the band 22,025 to 22,140 kilocycles, the antenna power is approximately 150 watts.

d. Type of Emission.—This transmitter is designed to provide A1 (continuous-wave) and A2 (modulated-wave) emission. For A2 emission, the modulated frequency is 500 cycles, and the modulation percentage is approximately 70 per cent.

e. Frequency Tolerance.—When the transmitter is used as a master-oscillator type of transmitter, a frequency tolerance of ± 0.05 per cent is maintained. When the transmitter is used as a crystal-controlled transmitter, a frequency tolerance of ± 0.02 per cent is maintained.

f. Master-oscillator Operation.—Continuous-frequency coverage within the bands specified above may be obtained when the transmitter is used for master-oscillator operation. Provision is made for accurately setting the master oscillator to the calibrated frequency by means of a scale which is 11 in. in diameter.

g. Crystal-oscillator Operation.—The transmitter is designed so that a maximum of 10 quartz crystals may be installed to provide crystal control. Each crystal may be used to obtain two, three, or four output frequencies whenever the assigned output frequencies are in harmonic relationship. For example, a 4,140-kilocycle crystal provides output on 4,140, 8,280, 12,420, and 16,560 kilocycles. The fundamental frequency of the crystal that is required for each output frequency may be determined from charts supplied by the manufacturer.

h. Vacuum Tubes.—The transmitter uses a total of four vacuum tubes, as follows:

- 1 RCA 807 as crystal or master oscillator.
- 1 RCA 807 as buffer amplifier or frequency multiplier.
- 2 RCA 813's as power amplifiers.

i. Type of Circuit.—A schematic circuit diagram, Fig. 13-16, shows the circuit arrangement. The RCA 807 oscillator grid circuit is connected to an 11-position switch. Ten of these positions select the appropriate crystal, whereas the eleventh automatically transfers the circuit to provide master-oscillator operation. The master-oscillator circuit is provided with four separate tuned circuits for the 4-, 5-, 6-, and 8-megacycle bands. Each of these separate circuits has its frequency controlled over the specified bands by means of a small vernier condenser, controlled from the front panel, and to which is attached the 11 in.

diameter calibration scale. For operation in the bands 11, 12, 16, and 22 megacycles, the master-oscillator circuits operate at fundamental frequencies in the 4-, 5-, 6-, and 8-megacycle bands, and frequency multiplication is obtained in the buffer stage.

The buffer stage, which uses one RCA 807, comprises a tapped tank inductance and three preset tank condensers, the necessary switching being obtained by means of an 11-position selector switch. Owing to the small amount of grid excitation required by the buffer stage, this stage operates efficiently as a frequency multiplier or as a fundamental amplifier.

The power-amplifier stage, which uses two RCA 813 tubes in parallel, comprises a tuned tank circuit consisting of a tapped inductance and a panel-controlled variable air condenser. The power-amplifier tank circuit is arranged so that it may be conveniently tuned to any of the specified frequency bands. The output of the power-amplifier stage is capacitively coupled to the antenna circuit by means of a variable antenna-coupling condenser.

For keying the transmitter, a high-speed keying relay is employed, which keys the oscillator, buffer, and power-amplifier stages. For A2, or modulated-wave, emission, the power-amplifier stage is plate modulated through a suitable modulation transformer which is connected to a source of 500 cycles from the motor-generator set.

Panel Controls and Instruments.

1. Test key.
2. A1-A2 switch.
3. Filament rheostat.
4. Oscillator band switch.
5. Crystal-m.o. switch.
6. Oscillator tuning.
7. Buffer band switch.
8. Power-amplifier band switch.
9. Power-amplifier tuning condenser.
10. Antenna-coupling condenser.
11. Filament voltmeter.
12. Plate ammeter.
13. Calibration chart.

j. Power Supply.—The ET-8019 transmitter is designed so that it may use the same motor-generator power supply that is normally employed with the shipboard intermediate-frequency transmitter such as the ET-8010 type. This motor generator consists of a motor for 110- or 230-volt direct-current supply, a 1,200-volt 0.45-amp. direct-current generator, and a 110-volt 1.59-amp. 500-cycle alternator. Collector rings are provided on the motor to furnish alternating current for filament supply. When the ET-8019 transmitter is furnished for use with the ET-8010 type of medium-frequency transmitter, a suitable power-

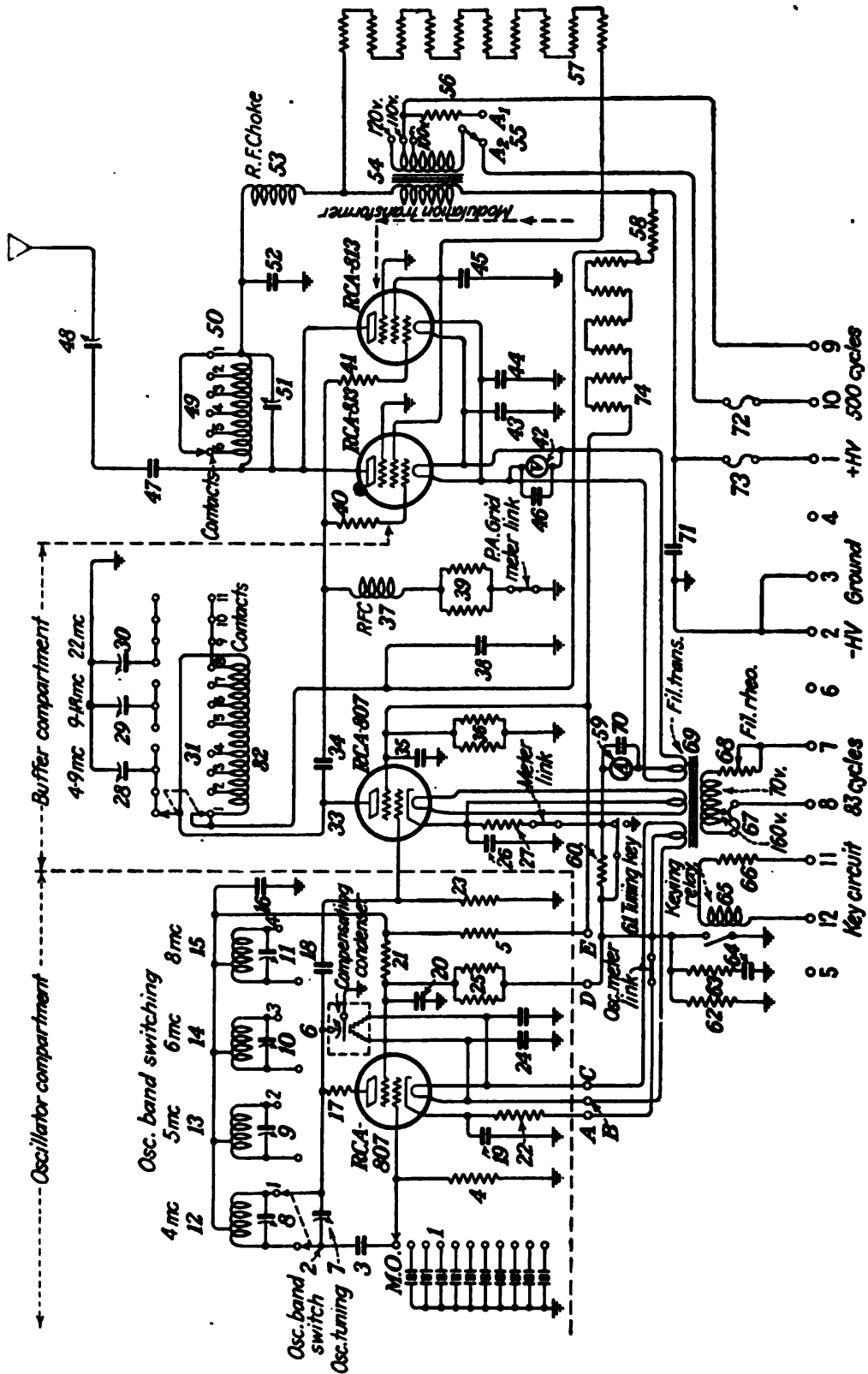


FIG. 13-16.—R.M.C.A. Model ET-8019 high-frequency radiotelegraph transmitter.

transfer switch is furnished to enable the motor generator to be used with either transmitter. The motor generator requires approximately 1,300 watts from the shipboard power supply.

k. Keying.—The keying of this transmitter is accomplished by keying the oscillator through a cathode resistor as shown in the schematic diagram. When the keying relay contacts, item 65, are open the plate, control-grid, and screen currents must flow through the blocking bias resistor, 62, to reach the cathode. Tracing the flow of this combined current, we see that it passes up from the ground through the cathode resistor, 62, through the oscillator-meter link, and the operating bias resistor, 22, to the cathode. The *IR* drop produced in these cathode resistors, 22, and 62, is added to the drop produced in the grid leak resistor, 4. This combined drop is sufficient to place a negative potential on the control grid great enough to block the tube and stop oscillations.

PARTS OF R.M.C.A. MODEL ET-8019 TRANSMITTER (See Fig. 13-16)

1. Crystal *M.O.* switch.
2. Oscillator band switch.
3. Grid stopping condenser, 0.00005 mf.
4. Oscillator grid leak, 50,000 ohms, 0.5 watt.
5. Oscillator screen-grid resistor, 1,000 ohm, 2 watt.
6. Oscillator compensating condenser.
7. Oscillator tuning condenser, 140 mmf.
- 8-11. Master-oscillator plate tank condensers for 4-, 5-, 6-, and 8-megacycle bands, 140, 140, 140, and 100 mmf., respectively.
- 12-15. Master-oscillator plate tank inductances.
16. By-pass condenser, 0.01 mf.
17. Antiparasitic resistor, 50 ohms, 5 watts.
18. By-pass condenser, 0.00005 mf.
19. By-pass condenser, 0.01 mf.
20. By-pass condenser, 0.001 mf.
21. Screen-grid voltage dropping resistor, 40,000 ohms, 5 watts.
22. Oscillator cathode resistor, 500 ohms, 2 watts.
23. Oscillator plate resistor, 40,000 ohms, 5 watts.
24. By-pass condensers (2), 0.01 mf. each.
25. Screen-grid resistor combination, 40,000 ohms, 2 watts.
26. By-pass condenser, 0.01 mf.
27. Cathode resistor, 3,000 ohms, 50 watts.
28. Buffer tuning condenser, 150 mmf. for 4-9 megacycles.
29. Buffer tuning condenser, 50 mmf., for 9-18 megacycles.
30. Buffer tuning condenser, 50 mmf., for 22 megacycles.
31. Buffer band switch.
32. Buffer plate-tank inductance.
33. Buffer tube.
34. Plate stopping condenser, 0.00005 mf.
35. By-pass condenser, 0.01 mf.
36. Screen-grid resistor combination, 100,000 ohms, 5 watts, each.
37. Radio-frequency choke.
38. By-pass condenser, 0.01 mf.
39. Buffer plate resistor combination, 10,000 ohms, 5 watts, eac.
40. Antiparasitic resistor, 50 ohms, 5 watts.
41. Antiparasitic resistor, 50 ohms, 5 watts.
42. Filament voltmeter, 0-15 volts.
43. By-pass condenser, 0.01 mf.
44. By-pass condenser, 0.01 mf.
45. By-pass condenser, 0.01 mf.
46. By-pass condenser, 0.01 mf.
47. By-pass condenser, 0.01 mf.
48. Antenna tuning condenser, 50 mmf.
49. Power-amplifier band switch.
50. Power-amplifier plate tank.
51. Power-amplifier plate tank tuning condenser, 150 mmf.
52. By-pass condenser, 0.002 mf.
53. Radio-frequency choke.
54. Modulation transformer.
55. Emission selector switch.
56. Primary shunt resistor, 75 ohms, 20 watts.
57. Voltage divider resistors, 10-5-watt resistors, 2,000 ohms each.
58. Voltage divider resistor, 1-100-watt resistor, 3,000 ohms.
59. Ammeter, d.c., 0-1 amp.
60. Keying resistor, 200 ohms, 100 watts.
61. Tuning key.
62. Keying resistor, 40,000 ohms, 5 watts.
63. Key filter resistor, 500 ohms, 0.5 watt.
64. Key filter condenser, 0.1 mf.
65. Keying relay.
66. Series resistor for keying relay.
67. Fuse, 3 amp.
68. Filament rheostat.
69. Filament transformer.
70. By-pass condenser, 0.01 mf.
71. By-pass condenser, 4 mf.
72. Fuse, 3 amp.
73. Fuse, 0.75 amp.
74. Voltage divider, six 1,500-ohm resistors, 5 watts, each.

When the keying relay contacts, 65, are closed the keying resistor, 62, is short-circuited and its voltage drop removed from the control grid, leaving only the normal operating bias produced by the IR drop in the grid leak and cathode resistors, 4 and 22. Hence, keying is accomplished by opening and closing the keying-relay contacts, 65.

1. Instructions for Radio Operator.—1. Careful attention to the following instructions will enable the radio operator to adjust the transmitter quickly to any one of its calibrated frequencies and to secure maximum overall performance.

2. In the case of a set installed for master-oscillator operation only, the crystal switch should be placed in the m.o. position. Then, by referring to the calibration chart, place the oscillator band switch, oscillator tuning, buffer band switch, and power-amplifier band switch in their correct positions. For example, to operate on 8,280 kilocycles (36-meter band), the crystal switch is placed in the m.o. position and the oscillator band switch in position 1. The buffer band switch is placed in position 4 and the power-amplifier band switch in position 2.

3. Adjust filament voltage to 10 volts and plate voltage to 1,200 volts. The plate-voltage adjustment will normally be made by means of the voltmeter and rheostat on the medium-frequency transmitter such as an ET-8010 type, when both the ET-8019 and ET-8010 are installed together with a common motor-generator set. A power-transfer switch, type PTS-1, is used to transfer the motor-generator circuits, and plate voltage should be adjusted for the ET-8019 by temporarily placing the PTS-1 switch in the medium-frequency (ET-8010) position. When the ET-8019 is used with a separate motor-generator set, a small control panel containing a start-stop switch, plate voltmeter, and a ganged generator and alternator field rheostat is provided.

4. Place the A1-A2 switch, 55, in the A1 position for continuous-wave transmission. Set antenna coupling condenser temporarily at zero, press the tuning key on the front panel, and adjust the power-amplifier tuning condenser for minimum power-amplifier plate current. Now gradually increase the setting of the antenna-coupling condenser and readjust the power-amplifier tuning condenser at the same time until the set loads out to approximately 0.3 to 0.4 amp. plate current. It is important to understand how to adjust the antenna coupling and power-amplifier tuning correctly. As the antenna coupling is increased, that is, when the pointer is moved toward higher readings, it is necessary to readjust the power-amplifier tuning toward higher readings in order to maintain the power-amplifier tank circuit in resonance. When the correct adjustment has been obtained, a change in the setting of either the antenna coupling or the power-amplifier tuning will cause an increase in plate current, the correct setting, of course, being the one that gives minimum plate current at a loaded-out value between 0.3 and 0.4 amp. It will be observed that as the antenna coupling is increased (pointer moving toward higher readings on the scale) the power-amplifier tuning becomes "broader," which is an indication that the set is loading out into the antenna.

5. The foregoing instructions with respect to the antenna-coupling and power-amplifier tuning adjustments apply primarily to initial adjustments, after which the appropriate settings may be recorded on the calibration chart for quick reset. It is emphasized that the power-amplifier tuning must always be kept in resonance, since if this circuit is detuned it is possible to obtain high power-amplifier plate current without the antenna circuit taking the load properly.

6. When crystals are furnished for crystal control, they should be plugged into the sockets provided at the top of the oscillator unit. Always install crystals so that the name plate on the crystal faces the front panel. The crystal sockets are numbered 1 to 10 to correspond to the first 10 positions of the crystal switch. The lowest frequency

crystals are plugged into the sockets bearing the lower number, as for example, a 4,130-kilocycle crystal goes in socket 1, 4,140-kilocycle in 2, 4,150-kilocycle in 3, 5,520-kilocycle in 4, and 6,210-kilocycle in 5. If additional crystals are used, a similar arrangement should be followed so that the higher numbers on the crystal switch conform to higher crystal frequencies.

7. The adjustments for crystal-oscillator operation are in all respects similar to those for master-oscillator operation with the exception that, in general, a higher setting of the oscillator tuning dial is required as compared with the setting for the same frequency for master-oscillator operation. For example, if the set is calibrated as a master oscillator for 8,280 kilocycles and the oscillator tuning dial is calibrated at say 150, then for crystal operation the oscillator dial would be set at about 165.

8. Correct performance with crystal control and satisfactory keying may be checked as follows. Assume that all switches and antenna-coupling and power-amplifier tuning adjustments are properly made. As the oscillator tuning dial is turned toward lower numbers, the crystal will "snap" out of oscillation and the power-amplifier plate current will increase. Now, if the oscillator tuning is carefully turned toward higher readings, a point will be reached where the crystal oscillator snaps in and the power-amplifier plate current will decrease. This adjustment may not give clean keying. The oscillator tuning should then be turned approximately 15 divisions higher on the scale, which will give clean keying and normal operation. Obviously, when the calibration chart is properly filled in, all the various dials and switches may be quickly set at the calibrated points.

9. If it is desired to use A2, or modulated, transmission, the panel switch should be placed in the A2 position. This will then modulate the power-amplifier tubes with 500-cycle energy from the alternator on the motor-generator set and provide a distinctive note which is useful for calling purposes or for handling traffic during fading conditions.

10. Always keep the sides of the set firmly fastened by means of the thumb screws which are provided. The inside of the transmitter should be kept free from dust or dirt, and switch contacts should be inspected occasionally to insure proper operation. Binding posts for meter connections inside the set, for use by the serviceman, are normally short-circuited by means of small jumper connections. These binding posts should be kept tight.

m. Service adjustments.—1. *Switch Positions.* Refer to the following table for correct switch positions for the various bands.

Band, kilocycles	Oscillator band switch	Buffer switch	Power-amplifier switch
4,140- 4,165	1	1	1
5,510- 5,535	2	2	1
6,210- 6,240	3	3	1
8,240- 8,330	1	4	2
11,020-11,070	2	5	3
12,360-12,480	3	6	3
16,480-16,660	1	7	4
22,025-22,140	2	8	5

Note that position 4 of the oscillator-band switch is not normally used. This band is included for future special applications. Also note that the 4,140- to 4,165-kilocycle oscillator band is used for that band as well as for the 8,240- to 8,330-kilocycle and the 16,480- to 16,660-kilocycle bands. In like manner, the 5,510- to 5,535-kilocycle band is used again for 11,020 to 11,070 and 22,025 to 22,140 kilocycle. In other

words, the frequency of the oscillator section is amplified by the buffer as a fundamental amplifier, or as a doubler, tripler, or quadrupler, depending upon the output frequency desired.

2. *Oscillator-band Centering.* The four oscillator bands are centered in the laboratory by means of four oscillator condensers which are mounted on the left side of the oscillator unit, locked, and covered with a small plate. Under normal circumstances, these four oscillator-band-centering condensers should not be tampered with or readjusted, as otherwise the correct coverage may not be obtained with the band-spread oscillator-tuning panel control. If, however, it is ever necessary to adjust any of the band-centering condensers, it is important that this adjustment be made with the oscillator-tuning dial set at the correct position. A typical calibration chart is supplied to show the approximate position of the main-oscillator-tuning dial for each of the various bands. Failure to observe this chart may result in inability to secure the proper oscillator frequency when the buffer functions as a frequency multiplier. For example, although the oscillator need cover only 4,140 to 4,165 kilocycle for output frequencies in *that* band, when the oscillator is adjusted to provide an output frequency of 16,480 kilocycles, then the oscillator must function at 4,120 kilocycles, which of course is below 4,140 kilocycles. In the same manner, an output frequency of 22,025 kilocycles requires an oscillator frequency of 5,506.25 kilocycles, which is below the lowest frequency of 5,510 kilocycles in the normal 5-megacycle band. These same considerations apply with respect to oscillator-band coverage in the various other bands provided by the set.

3. When the ET-8019 transmitter is furnished with crystals, it is important for the installation engineer to understand the proper procedure in calibrating the oscillator-tuning dial to insure stable crystal-oscillator operation and clean keying. Sets shipped with crystals are of course calibrated, and the calibration is entered on the chart so that the procedure outlined below need not be repeated. However, in the event of additional crystals being installed at a future date, carefully observe the following instructions.

(a) Insert a 0 to 50 milliammeter across the oscillator-meter links in the rear of the set.

(b) Temporarily disconnect the antenna from the set.

(c) Insert crystals in the crystal sockets, making sure the name plate on the crystal faces the front panel. Crystal sockets are numbered to correspond to the equivalent oscillator switch positions, and the crystals should be inserted with the lowest frequency crystals in the lower numbered sockets. For example, a 4,130-kilocycle crystal goes in socket 1, and a 6,120-kilocycle crystal goes in socket 5 for sets furnished with five crystals, as before explained.

(d) Place all switches in their correct positions and the power-amplifier tuning condenser at a scale reading as shown on the typical calibration chart supplied. This chart is based on a power-amplifier tuning adjustment with *no antenna* for convenience of the engineer in setting the power amplifier at resonance.

(e) Adjust plate voltage to normal value of 1,200 volts. Now momentarily press the test button on the transmitter panel. If the oscillator-tuning adjustment is such that the crystal is not oscillating, the power-amplifier plate current will be high, around 350 ma. Now as the oscillator-tuning knob is turned, the crystal will snap into oscillation and the power-amplifier plate current will drop to a low value of approximately 100 ma. The power-amplifier tuning condenser may now be readjusted for a more accurate minimum. Next, observe the oscillator plate current and note that as the oscillator dial is turned the plate current in the oscillator will dip to approximately 22 ma. Now turn the oscillator-tuning dial toward *higher* readings until the oscillator plate current is approximately 3 ma. higher than its minimum value or about 25 ma. Then check the note in the ship's short-wave receiver by keying the

set rapidly to observe if good clean-cut keying is obtained. This final setting of the oscillator-tuning dial, namely, about 3 ma. higher than minimum oscillator plate current, should be the value to record on the calibration chart. It will be observed that crystals will oscillate over a very wide range on the oscillator-tuning dial as long as the dial is rotated toward *higher* readings. However, the calibration should not be recorded for too high a dial setting above that which gives minimum oscillator plate current, as this will reduce the drive on the buffer. If it is necessary to adjust crystals without a 0- to 50-ma. oscillator meter, it is possible to make the adjustment using the main plate meter on the panel. This is done by slowly turning the oscillator-tuning dial starting at zero until a setting is reached where the power-amplifier plate current suddenly drops. Then the oscillator-tuning dial should be advanced to a higher reading by approximately 15 scale divisions and this new setting recorded as the correct crystal-oscillator calibration. Beat-note check on short-wave receiver should also be made to insure good keying.

4. *Master-oscillator Calibration.* Sets furnished without crystals or sets with crystals that are to be calibrated for additional master-oscillator frequencies should be calibrated in the usual manner with a suitable frequency meter. All switches and the power-amplifier tuning adjustments should be set as shown on the typical calibration chart. Considerable band spread is provided on the oscillator-tuning dial so that the various frequencies in each band may be readily calibrated and reset with accuracy.

The normal total band coverage of each oscillator range, based on an oscillator dial setting of 150 for the calling frequency in each band, is as follows (calling frequencies are 4,140, 5,520, 6,210, 8,280, 11,040, 12,420, 16,560, and 22,080 kilocycles:

Oscillator Band	Kilocycle Range
1	4,060-4,180
2	5,420-5,580
3	6,100-6,275
4	8,100-8,390

Note: Oscillator-tuning dial has a "stop" at 410 divisions.

5. *Power-amplifier and Antenna-coupling Adjustment.* Inasmuch as the correct adjustment for the power-amplifier tuning and the antenna coupling depends upon the antenna characteristics, these adjustments cannot be made in the laboratory and must be determined aboard ship when the installation is made. The following procedure applies: Normal full-load power-amplifier plate current will range from approximately 0.3 to 0.4 amp. Start out with all band switches in their correct positions, and with the antenna coupling condenser set at zero. Tune the power amplifier for minimum plate current. Now adjust antenna coupling to a higher scale reading, which will raise the plate current, and then readjust the power-amplifier tuning to a higher scale reading, which will lower the plate current again. Continue this procedure until the power-amplifier plate current is not more than 0.4 amp. As the antenna takes more load, the power-amplifier tuning becomes broader, but in all cases the correct adjustment for both antenna coupling and power-amplifier tuning must be maintained. The adjustment for any frequency may be readily checked, after the set has been loaded out properly, by noting that the power-amplifier plate current will increase whenever the antenna coupling or the power-amplifier tuning are varied from their correct settings.

6. *Buffer Plate-current and Power-amplifier Grid-current Metering.* A pair of meter links for the buffer plate circuit is provided on the same mounting board as those previously mentioned for the oscillator. Average buffer plate current for normal operation is approximately 75 ma. A pair of meter links to insert a power-amplifier grid milliammeter is provided underneath the power-amplifier compartment at the

right rear. Normal power-amplifier grid current will vary from approximately 8 to 25 ma., depending upon the frequency band.

7. Buffer-tank-circuit Adjustments. The buffer-tank circuit consists of an inductance with taps connecting to the 11-position buffer switch and three variable air condensers as shown in Fig. 13-16. Only eight positions of the buffer switch are used for the normal frequency bands, the remaining three being strapped to position 8. The three variable air condensers in the buffer stage are carefully adjusted in the laboratory for maximum performance and should not be changed. However, if any of these condensers require readjustment in the field, the following procedure should be used: Always make adjustments beginning with the highest frequency in each band. For example, to adjust the 22-megacycle band, place all switches and dials in the correct positions, connect a power-amplifier grid milliammeter, and then carefully rotate the 22-megacycle tank condenser for maximum power-amplifier grid current. The 22-megacycle condenser is the one nearest the front panel. Next adjust the 16-megacycle band (center condenser) by turning this condenser for maximum power-amplifier grid current. After this has been done, check power-amplifier grid current in the 11- and 12-megacycle bands with all switches in correct positions, and if it is found that power-amplifier grid current is less than 8 ma. in the 11- or 12-megacycle bands, then the condenser may be slightly readjusted. Always check all the bands used with a given condenser so that the best overall setting may be obtained. It will be noted that the first four bands, namely, the 4-, 5-, 6-, and 8-megacycle bands, all use the same condenser setting (right-hand condenser), while the 11-, 12-, and 16-megacycle bands are all covered by the center condenser. The condenser nearest the panel is used solely for the 22-megacycle band.

8. Tuning Key. The tuning key on the front panel, when pressed, inserts resistance in the cathode of the power-amplifier and buffer stages, and automatically short-circuits this resistance when the button is in its OPEN position. Operation of the tuning key also performs the same functions as the contacts on the keying relay. The power output of the set is, therefore, lower when the tuning key is used than when the regular telegraph key is employed. All tuning should always be done on A1 rather than A2 emission. The purpose of the cathode resistor which is inserted by the tuning key is to protect the tubes from overload in the event that the power-amplifier tuning condenser has not been properly adjusted.

9. Power-transfer Switch. Since in many installations the ET-8019 transmitter is used with an ET-8010 type of set, a suitable power-transfer switch known as type PTS-1 is used. This switch transfers the alternating-current collector-ring circuit, the 500-cycle circuit, the telegraph key, and the negative high-voltage circuit to either type of transmitter as required.

10. ET-8019 Control Panel. For applications where the ET-8019 transmitter is used with its own motor-generator set, a suitable control panel is required. This panel contains a start-stop switch, ganged generator and alternator field rheostats, and a plate voltmeter.

This high-frequency transmitter is typical of the type of equipment used to establish communication from ship to shore over distances in excess of those covered by intermediate-frequency equipment.

2. MACKAY SHIP RADIOTELEGRAPH TRANSMITTER 136-A. *a. General Description.*—Radio transmitter 136-A is a complete, self-contained, high-frequency transmitter, containing all parts with the exception of the generator and hand key. It is entirely controlled from the front of the panel. A self-excited, temperature-compensated oscillator, housed in a metal compartment in the base of the transmitter, generates oscillations

on any one of three fundamental bands. This frequency is doubled at will, once, twice, or three times by the use of one, two, or three doubler circuits. A radio-frequency voltage of the frequency thus developed is used to drive two tubes in parallel in the amplifier stage of the transmitter. Type 6L6 tubes are used in all stages except the oscillator, which is a type 76 tube. The oscillator dial is calibrated, and tuning charts are furnished with each transmitter affording operation on any of seven marine bands. A schematic circuit diagram is shown in Fig. 13-17.

The heaters of all the tubes and three parallel connected ballast tubes are connected in series. This circuit operates directly across the 110-volt direct-current line. The ballast tubes serve to maintain the current through the heaters fairly constant over a wide range of voltage change.

The frequency of the transmitter is determined by an electric oscillator. Great care has been taken in the design of this oscillator to minimize the effects of expansion and contraction of the oscillator components caused by temperature changes. Variation in frequency caused by temperature changes has been greatly reduced by the use of a compensator condenser which is adjusted to counteract frequency changes over a wide range of temperature. The adjustments for this compensator and for the main band-setting condenser are on top of the oscillator compartment. These elements are precisely adjusted and sealed and should in no wise be altered. Should there be discrepancies, as explained below, the fact is called to the attention of the maintenance inspector who corrects the tuning or compensation, if required.

Each doubler or amplifier stage has its independent tuning adjustment, arranged progressively above the oscillator-tuning dial. The number of doublers to be used for any desired frequency is selected by means of the DOUBLER SW to the left and slightly above the 2D DOUBLER dial. This switch, in addition to connecting in circuit the proper doublers, also connects the output of the last doubler in use to the input of the amplifier circuit. The AMP. PLATE knob, above the ANT. COUPLING control, is always placed in a position corresponding to the DOUBLER SW. Should two doublers be in use, the DOUBLER SW will be in position 2, and the AMP. PLATE switch will also be in position 2. This second switch places in the plate circuit of the amplifier the proper inductance to cover the frequency range included in the second doubler's band.

The amount of inductance in the amplifier plate circuit is determined by the three clips attached to the upper contacts of the AMP. PLATE switch. The clip from position 1, the lowest frequency, attaches to the fourth, fifth, or sixth turn from the rear of the amplifier plate coil. This coil is wound on a ceramic form at the top of the subpanel assembly. Position 2 attaches to the fourth, fifth, or sixth turn from the front end of the coil, and position 3 to the second turn from the front end of the coil. Care should be taken not to cause frequency doubling in the amplifier

stage by using too little plate inductance and finding the resonant dip in plate current on the second harmonic of the frequency at which the grid is being driven. The most turns should be used in the plate inductance which will show a resonant dip on all frequencies which must be covered by the particular switch contact being adjusted, with the antenna coupled to the transmitter.

PARTS OF MACKAY SHIP RADIOTELEGRAPH TRANSMITTER 136-A (See Fig. 13-17)

Symbol	Description	Symbol	Description
C ₁	Mica condenser, 0.002 mf., 1,000 volts.	L ₁	Oscillator coil.
C ₂	Mica condenser, 0.002 mf., 1,000 volts.	L ₂	Oscillator coil.
C ₃	Mica condenser, 0.002 mf., 1,000 volts.	L ₃	First doubler coil.
C ₄	Mica condenser, 0.0001 mf., 2,500 volts.	L ₄	Second doubler coil.
C ₅	Mica condenser, 0.01 mf.	L ₅	Third doubler coil.
C ₆	Mica condenser, 0.01 mf.	R ₁	Carbon resistor, 100,000 ohms, 1 watt.
C ₇	Tuning condenser, 50 mmf.	R ₂	Carbon resistor, 1,000 ohms, 10 watts (Ohmite).
C ₈	Tuning condenser, 365 mmf.	R ₃	Carbon resistor, 25,000 ohms, 5 watts.
C ₉	Mica condenser, 0.01 mf.	R ₄	Carbon resistor, 50,000 ohms, 2 watts.
C ₁₀	Mica condenser, 25 mmf.	R ₅	Carbon resistor, 1,000 ohms, 10 watts (Ohmite).
C ₁₁	Mica condenser, 0.01 mf.	R ₆	Carbon resistor, 25,000 ohms, 5 watts.
C ₁₂	Mica condenser, 0.002 mf., 1,000 volts.	R ₇	Carbon resistor, 50,000 ohms, 2 watts.
C ₁₃	Mica condenser, 0.002 mf., 1,000 volts.	R ₈	Carbon resistor, 1,000 ohms, 10 watts (Ohmite).
C ₁₄	Mica condenser, 0.002 mf., 1,000 volts.	R ₉	Carbon resistor, 25,000 ohms, 5 watts.
C ₁₅	Mica condenser, 25 mmf.	R ₁₀	Vitreous enamel resistor, 350 ohms, 55 watts.
C ₁₆	Variable condenser, 140 mmf.	R ₁₁	Carbon resistor, 8,000 ohms, 10 watts.
C ₁₇	Mica condenser, 0.01 mf., 2,500 volts.	R ₁₂	Vitreous enamel resistor, 150 ohms, 25 watts.
C ₁₈	Mica condenser, 0.002 mf., 1,000 volts.	R ₁₃	Power resistor, 7,000 ohms, 20 watts.
C ₁₉	Mica condenser, 0.002 mf., 1,000 volts.	R ₁₄	Power resistor, 13,000 ohms, 20 watts.
C ₂₀	Mica condenser, 0.002 mf., 1,000 volts.	R ₁₅	Power resistor, 10 ohms, 20 watts.
C ₂₁	Mica condenser, 0.002 mf., 1,000 volts.	R ₁₆	Carbon resistor, 5,000 ohms, 2 watts.
C ₂₂	Mica condenser, 0.002 mf., 1,000 volts.	R ₁₇	Carbon resistor, 5,000 ohms, 2 watts.
C ₂₃	Mica condenser, 18 mmf., 1,000 volts.	R ₁₈	Carbon resistor, 5,000 ohms, 2 watts.
C ₂₄	Variable condenser, 140 mmf.	R ₁₉	Carbon resistor, 10,000 ohms, 5 watts.
C ₂₅	Mica condenser, 0.01 mf., 2,500 volts.	R ₂₀	Vitreous enamel resistor, 2.5 ohms, 10 watts.
C ₂₆	Mica condenser, 0.002 mf., 1,000 volts.	R ₂₁	Carbon resistor, 10,000 ohms, 1 watt.
C ₂₇	Mica condenser, 0.002 mf., 1,000 volts.	R ₂₂	Rheostat, 800 ohms, 15 amp.
C ₂₈	Mica condenser, 0.002 mf., 1,000 volts.	S ₁	Inductor switch.
C ₂₉	Mica condenser, 0.002 mf., 1,000 volts.	S ₂	Doubler switch.
C ₃₀	Mica condenser, 0.002 mf., 1,000 volts.	S ₃	Amplifier plate switch.
C ₃₁	Variable condenser, 140 mmf.	S ₄	Plate current switch.
C ₃₂	Mica condenser, 0.01 mf., 2,500 volts.	S ₅	Filament power switch.
C ₃₃	Variable condenser (midget), 140 mmf.	S ₆	Line switch to motor generator.
C ₃₄	Mica condenser, 0.002 mf., 1,000 volts.	M ₁	Weston thermo-ammeter, 0-0.5 amp.
C ₃₅	Mica condenser, 0.002 mf., 1,000 volts.	M ₂	Weston Direct-Current milliammeter, 0-300 ma.
C ₃₆	Temperature-compensating condenser.	M ₃	Weston Direct-Current voltmeter, 0-500 volts.
C ₃₇	Mica condenser, 0.01 mf., 2,500 volts.	RFC's	National R-100 radio-frequency choke.
C ₃₈	Mica condenser, 0.01 mf., 1,000 volts.		
F	Fuse, renewable enclosed type, 250 volts, 20 amp.		

Antenna coupling is provided by a variable condenser, marked ANT. COUPLING, which is tapped directly to the amplifier-plate inductance at the proper point to provide maximum output. Inasmuch as it is impos-

sible to anticipate antenna characteristics in advance, this adjustment of C_{39} must be made at the time of installation by the installer.

The clip attached to the bottom contact of the AMP. PLATE switch corresponding to the number of doublers in use, as explained in the preceding paragraph, should be connected near the plate end of the amplifier-plate coil. The plate end of the coil is the end nearest the front panel. The antenna-coupling condenser and the amplifier-plate tuning condenser should be adjusted at the same time until maximum antenna current is indicated on the antenna meter.

Beginning with the ANT. COUPLING control at 0, its setting should be gradually increased, at the same time readjusting the AMP. TUNING control to minimum plate current, until the amplifier-plate current shows approximately 180 ma. at the bottom of its dip, with a plate voltage of 450 volts, which should never be exceeded. Plate voltage is adjusted by means of the field rheostat located at the upper left of the panel.

If the amplifier-plate current does not rise to approximately 180 ma. when the amplifier-plate current is at the bottom of its dip, the aforementioned clip should be moved nearer the plate end of the inductance. If the amplifier-plate current rises to too high a value, the clip should be set nearer the low potential end of the inductance.

Panel meters are provided to read plate voltage and current. A third meter mounted above the transmitter reads the antenna current. The plate voltmeter, which is connected across the high-voltage leads from the generator, reads the generator-output voltage at all times when the machine is running. Directly below the plate voltmeter is the generator-field rheostat, which controls the voltage to the transmitter.

The PLATE CURRENT meter reads the current flowing in the plate circuit of any stage, including the oscillator. The stage in which it is desired to read the plate current is selected by the control marked PLATE CURRENT, which knob is located to the right of the 1ST DOUBLER control.

Keying is accomplished by short-circuiting a bias resistor R_{13} , which removes from the grid circuits of all the tubes a bias which renders them inoperative. This arrangement places only a low voltage across the key. Choice of circuit constants results essentially in "thumpless" keying.

There are two control switches. The switch to the left marked FILAMENT connects the heaters of all the tubes to the direct-current line. The right-hand switch marked PLATE starts the direct-current generator which supplies the plate voltage. The plate switch will not function until the filament switch has been closed. The plate switch may be operated immediately after the filament switch, and the transmitter may then be keyed in approximately 15 sec., which is the time required for the filaments to reach full emission.

Since a slight frequency drift may be experienced in the first 15 sec. after energizing the filaments, it is advisable not to start the plate motor

generator until after at least that period of time to minimize such drift. It is good practice to anticipate schedules or periods of transmission and energize the filaments several minutes ahead of time, if possible. During periods of listening or other intervals between transmission, the plate motor generator may be switched off, allowing the filaments to remain heated in a condition for instant service.

Fuse protection is provided in both the direct-current line and high-voltage circuits. The high-voltage fuse is placed in the positive leg of the generator output. Both sets of fuses are mounted on the transmitter base, in the rear of the oscillator unit.

b. Installation Instructions.—Radio transmitter 136-A is intended to be mounted on the operating table or on a stand. The transmitter is held down by bolts through the wood frame upon which it is mounted. No external shockproofing need be used, as rubber shockproof mountings are used between the transmitter and its wood mounting frame.

Motor generator 111-C should be placed as far from the receiver as possible, and all wiring should be lead covered or otherwise shielded, the sheathing and generator frame being substantially grounded. The ground lead to the receiver should not be used to ground the generator or cable sheathing. A separate ground should be run directly to the generator and cabling. Number 14 wire, 600-volt insulation, should be used for all leads except that running from the positive terminal of the generator to transmitter terminal 6. This lead should be No. 14, insulated for at least 1,500 volts.

The ground connection from the transmitter should be as short as practically possible, in order to keep the transmitter frame as near zero potential as possible.

c. Operating Instructions.—To place the transmitter in operation, turn the field rheostat all the way to the left (minimum voltage). Close the FILAMENT switch. The green light above the switch should light, indicating that all tubes are in circuit. After 15 sec., close the PLATE switch. Adjust the plate voltage by means of the field rheostat to read not over 450 volts.

The operating frequencies, as explained, are obtained by securing multiples of the oscillator frequency and driving the amplifier at this harmonic frequency. The oscillator functions, as before stated, on three fundamental frequency bands, which may be doubled once, twice, or three times, as required. To simplify monitoring, as explained hereafter, a curve is furnished for each frequency band, with the calling frequency marked clearly.

There are seven curves, one for each frequency range. Each of the curves is divided into two sections in order to spread the scales out and make them easier to read. Each section of the curve is almost a straight line. The axes are marked USE LOWER CURVE and USE UPPER CURVE to indicate which section to use. Observe care to read each section of the curve on its proper axis. On all curve sheets, one small division on the horizontal scales corresponds to five divisions of the red pointer on the dial. On the 5-, 6-, and 8-megacycle bands, one small vertical division is 1 kilocycle. On the 11-, 12-, and 16-megacycle bands, one small division is 2 kilocycles, and on the 22-megacycle band, one small division is 4 kilocycles.

Referring to the ship radio-station license covering assigned frequencies in the high-frequency marine bands, the transmitter should be adjusted to the desired "calling" frequency. If it is necessary to shift to another assigned marine frequency, careful reference should again be made to the calibration chart. This is to guard

against transmitter operation on frequencies other than those for which the station is licensed.

For convenience, the oscillator and doubler switch settings for the frequency bands are listed herewith.

Oscillator band	Doubler switch	Frequency range, kilocycles
1	1	Unused
	2	8,200- 8,500
	3	16,400-16,980
2	1	5,500- 5,700
	2	11,000-11,400
	3	22,000-22,800
3	1	6,160- 6,410
	2	12,300-12,820
	3	Unused

For example, should it be desired to operate on 8,280 kilocycles (the 36-meter band), the oscillator dial is adjusted to the setting shown on the curve for this frequency. The OSCILLATOR PLATE switch is placed in position 1. It is necessary to double this frequency twice to obtain the necessary frequency in this case. Place the DOUBLER SW and the AMP. PLATE switches both on position 2. To resonate the first doubler, place the PLATE CURRENT switch on position 2. Close the sending key. Turn the 1ST DOUBLER dial. At about 70 on this dial, the plate current of the second doubler will rise slightly. This rise indicates resonance of the first doubler. Now place the PLATE CURRENT switch on A position and resonate the 2D DOUBLER. The plate current should rise to a value somewhat in excess of 200 ma. when the 2D DOUBLER is resonated, provided the amplifier is off resonance. Resonance of the second doubler at this frequency should appear in the neighborhood of 95 degrees on its dial. Leaving the plate current meter on position A of the PLATE CURRENT switch, now adjust the AMP. TUNING knob. At some position, the current indicated on the plate meter will dip to a rather low value. This indicates resonance of the amplifier. The antenna coupling is now adjusted by the ANT. COUPLING control. The antenna meter located atop the transmitter will read a maximum value at some point on the ANT. COUPLING dial, provided the antenna tap for this frequency is properly located on the plate inductance. At the time of original tuning, the antenna tap corresponding to the switch setting should be placed on the plate inductance turn which provides best output for the frequencies served by this switch tap. A few trials will determine the proper turn to use. It is possible that in all cases the antenna tap will be near the plate end. The antenna meter may or may not read much current, and the extent of its reading is of no consequence except in obtaining loading of the amplifier. When the antenna circuit is properly adjusted, the antenna meter will read a maximum for that frequency, though the actual value may vary greatly on different bands. As the antenna-coupling-condenser capacity is increased from 0, the amplifier-plate current meter will indicate a rise in current, which, when the circuit is well loaded, will approximate 180 ma. Adjustment of the ANTENNA COUPLING control will react somewhat on the AMP. TUNING; so it will be necessary to readjust first one and then the other until maximum output with minimum plate current is indicated. A slight readjustment of the doubler dials may result in still greater output. The transmitter is now

ready for operation. Should it be desired to operate in some other part of the same marine band, the oscillator dial can usually be set to that point without the necessity of readjusting the other controls.

A sheet of recommended settings is supplied. The oscillator setting shown on this sheet is the calling frequency for each band. The settings for AMP. TUNING and ANT. COUPLING are necessarily left blank to be filled in at installation. These settings may vary slightly from time to time depending upon the condition of the antenna with respect to moisture, ice, and other unusual conditions. A swinging antenna may cause varying amplifier-plate current, which ordinarily does no harm unless the maximum swing is in excess of 200 ma., when it would be desirable to decrease the setting of the antenna-coupling condenser to keep the maximum swing below this value.

As another example of adjustment, consider operation on the 5,500-kilocycle band. This requires only one doubler. Place both the doubler switch and the amplifier-plate switch on position 1. The oscillator plate control is set on position 2 and the oscillator dial placed on the proper point for the desired frequency of operation, in accordance with the calibration curve. Place the PLATE CURRENT meter switch on position A, and adjust the 1ST DOUBLER dial for maximum reading on the plate current meter, indicating resonance of the 1ST DOUBLER. Adjustment of the antenna circuit and resonance of the final stage plate circuit are as explained heretofore.

To operate on the third doubler, or the eighth harmonic of any of the three frequencies of the oscillator, the DOUBLER SW and AMP. PLATE switches are placed on position 3, the oscillator having been placed on the proper frequency as explained. The stages are now resonated successively, the meter being placed in doubler stage 2 when adjusting doubler 1, in stage 3 when adjusting doubler 2, and in the amplifier stage when adjusting doubler 3. Antenna adjustment is accomplished as heretofore.

d. Description of Oscillator Adjustments.—The component parts of the oscillator are carefully chosen, *Mycalex* and *Isolantite* being used where the characteristics are important, the use of materials of poor electrical or mechanical characteristics being avoided. It is to be expected that an aging effect will take place, however, over a long period of time, which will gradually shift the calibration. This effect can be observed by a periodic check against land-station frequencies. When the oscillator is produced at the factory, it is placed in a chamber whose temperature can be controlled over a wide range. Observations are made of frequency change with temperature. If the frequency decreases with rising temperature, the bimetallic compensating condenser capacity is increased, and vice versa. The compensating condenser is then locked and sealed in a position that causes the frequency to rise with temperature until 30° C. is reached, beyond which point the frequency decreases with further temperature rise. This results in a maximum frequency deviation of about 2.3 parts per million per degree centigrade over the range of 13 to 43°C. Thus, it will be seen that the setting of this compensating condenser should not be disturbed. It will be of interest to the operator, however, to note deviations caused by temperature changes from winter to summer or over extremes of temperature as checked against coast-station frequencies.

It will be noticed that the marine band is only a small portion of the oscillator-frequency coverage in each of its ranges. The oscillator ranges are extended to cover coast-station frequencies for the purpose of monitoring this transmitter by listening to the oscillator note in the receiver and comparing its frequency, as charted on the curves, with that of known coast-station frequencies. In order to reduce the intensity of the signal from the transmitter in the receiver to a value that does not overload the receiver, the output of the transmitter is reduced by detuning the first-doubler dial to one side or the other of resonance. This will provide a comfortable signal in the receiver without otherwise disturbing the transmitter adjustments. The coast-station whose frequency is known is tuned to zero beat on the receiver. The oscillator

is then placed on a band corresponding to the coast-station frequency and adjusted until zero beat from the oscillator in the receiver falls upon the zero beat of the coast station. Exact determination of zero beat can be facilitated by reducing the receiver regeneration to a point just below oscillation and causing the oscillator to beat directly with the coast-station frequency. If consistent errors of greater than 15 divisions of the red hand are noticed on several coast stations, the oscillator setting may need correction by allowing for the error in adjusting transmitter frequency.

The regulations of the FCC state that in the United States a high-frequency coast station shall be within 0.04 of 1 per cent of its assigned frequency. The mobile marine station shall be within 0.1 of 1 per cent of its assigned frequency. In order to be sure that the calibration of the oscillator is within the required tolerance when checking the curve against a coast station, the oscillator-calibration dial reading must show a frequency for the coast station within the limits of the difference of these tolerances or ± 0.06 of 1 per cent. This corresponds to ± 22 divisions of the red pointer. In spite of careful frequency control of coast stations, it occasionally happens that one will drift to a frequency deviation in excess of its tolerance. It is therefore advisable to check against several coast stations and apply a correction which is a result of averaging the deviations of all coast stations checked, neglecting, of course, to include the deviation of any coast station which is obviously much in excess of the others. To be within a conservative margin of tolerance, if the average deviation of readings taken on a number of coast stations is in excess of 15 divisions of the oscillator dial, this average deviation should be applied to the calibration curves of the oscillator by adding or subtracting the number of degrees of the deviation to the calibration curves, or by drawing up new curves which are offset from the original calibration by the number of degrees of the deviation. Oscillator range 1 covers the 8,000-kilocycle band and also the 16,000-kilocycle band. Therefore, coast stations in either band may be used to check this range. Range 2 covers the 5,000, 11,000- and 22,000-kilocycle bands, and stations in any of these bands may be used to check this range. Similarly, range 3 covers the 6,000- and 12,000-kilocycle bands, and stations in either of these bands will check this range.

The following procedure should be followed in making a check of the oscillator calibration. Tabulate the differences between the settings of the oscillator dial as actually read and those read from the curve for the frequencies of several land stations of known frequency. These stations may be in different bands covered by the one oscillator range being checked, as explained above. Add the differences and divide by the total number of stations used in making the observations. If the average deviation thus obtained is greater than 15 divisions, a correction should be applied. Suppose five stations are used for checking, designated as stations A, B, C, D, and E. If dial readings are lower than curve readings, deviation is minus; if higher, plus.

	Station				
	A	B	C	D	E
Divisions of difference between dial reading and curve.....	+7	-3	+5	-6	-9
Sum of differences.....	+7 - 3 + 5 - 6 - 9 = -6				
Divide by number of stations.....	-6 divided by 5 = -1 1/5 average deviation				
This indicates that the oscillator calibration is not in need of correction.					

Another example:

	Station				
	A	B	C	D	E
Divisions of difference between dial reading and curve.....	+22	+18	+17	+7	+40

Note: Ignore station E because of its wide variation in setting from other stations.

Sum of differences..... $+22 + 18 + 17 + 7 = +64$
 Divide by number of stations..... $+64$ divided by 4 = $+16$ average deviation

This is an average deviation greater than 15 and indicates that 16 divisions should be added to the dial reading as shown on the curve to set to any desired frequency, or a new curve should be drawn with all the dial readings 16 divisions higher than the old curve.

Changes in oscillator calibration may result from the long-time aging effect mentioned above, from injury to the parts or loosening of bolts, or other unpredictable causes. For this reason, a routine of frequent checking of the oscillator should be observed in order to obtain the optimum performance of which the equipment is capable. It is probable that a reduction of the present 0.1 per cent tolerance for mobile stations will sooner or later be put into effect, in which case correspondingly greater care must be used in frequency setting.

In setting the oscillator, the necessary limitations of a dial of this type must be considered. The black pointer is connected directly to the condenser shaft. The red pointer is driven by a gear reduction providing 100 divisions per revolution and 18 revolutions to cover the 18 divisions of the black pointer. These gears are designed to reduce backlash to a minimum, but backlash of approximately $2\frac{1}{2}$ divisions of the red pointer is necessarily present because of the high reduction. No advantage is present therefore in setting or reading closer than to one division of the red pointer.

e. Possible Sources of Trouble.—Tube failures should be few except as may occur after some length of time. The ability to read instantly the current in the plate circuit of any tube facilitates determining which tubes may be poor. Should there be normal drive on one stage, but not on the next, or should one doubler operate better than two doublers, it is apparent that the second doubler tube is poor. All doublers should provide about equal drive to the amplifier; that is, the plate current in the amplifier stage should be "pushed" up to nearly the same value by one doubler or by three. If this is not the case, the offending stage can be readily detected.

Since the tube filaments are in series, the failure of any one tube will cause the green pilot lamp to be extinguished. By successively replacing the tubes until the pilot lamp again lights, the faulty tube can be quickly determined. Should a ballast tube become defective, it will be apparent by the other two ballast tubes glowing more brightly. It is well to check these tubes occasionally. Low plate current or slow tube heating may be caused.

A tube failure may result in blowing of the high-voltage fuse. This will be indicated immediately by the presence of plate voltage but no current in any stage.

13.8. Coastal-harbor Radiotelephone Equipment.—Coastal-harbor radiotelephone stations are maintained at various coastal and Great Lakes cities. Through these stations, connections are made to the land-telephone system so that conversations may be carried on from ship to shore and from shore to ship.

R.M.C.A. MODEL ET-8012-B RADIO TRANSMITTER.—This transmitter is designed for communication between a ship and a coastal-harbor radiotelephone station and also for intership (ship-to-ship) communication. The equipment comprises a complete radio transmitter and receiver and the necessary motor generators, all mounted in a single cabinet.

a. General Description.—In order to carry on communication with particular harbor station, or with another vessel, it is necessary to set radio transmitter and receiver of the ET-8012-B to the appropriate transmitting and receiving frequencies. A list of the correct switch position for the various frequencies and harbor stations is supplied with equipment.



FIG. 13-18.—R.M.C.A. Model ET-8012-B radiotelephone equipment. (Courtesy R.M.C.A.)

Before operating the equipment, the user should become familiar with the various controls on the panel of the cabinet. This may be done by referring to the photograph in Fig. 13-18 or by viewing the actual unit. The radio transmitter is located in the upper section of the cabinet. Two meters are provided, one of which reads the current delivered to the antenna (antenna current) whereas the other indicates plate current. Between the two meters, there is a large knob marked *ADJUST FOR MAXIMUM ANTENNA CURRENT*. This knob is used to rotate

a coil inside the set which tunes the antenna circuit for maximum antenna current for the particular transmitting frequency that is to be used.

The 10 frequencies for which the transmitter may be tuned are controlled by means of a 10-position switch marked TRANS, this switch being located directly below the antenna current meter. A switch marked HANDSET SWITCH, mounted below the antenna-tuning control, is used to select either PRESS-TALK operation or AUTOMATIC operation. When this switch is in the PRESS-TALK position, it allows the push button in the handle of the telephone handset to transfer the various circuits from transmitting to receiving, or vice versa. In other words, when the push button is depressed, the transmitter goes "on the air." When the push button is released, the transmitter goes off the air and the radio receiver is connected in the circuit. When the HANDSET switch is placed in the AUTOMATIC position, send-receive operation is accomplished automatically whenever speech is impressed on the microphone of the handset. The user may employ either PRESS-TALK or AUTOMATIC operation as he prefers. AUTOMATIC operation makes it unnecessary for the user to remember to press or release the push button. On the other hand, PRESS-TALK operation will be found to provide better communication under adverse conditions since it eliminates the possibility of interruption in outgoing speech which is cut off automatically during pauses between words or syllables if AUTOMATIC operation is used.

The meter switch marked CURRENT mounted below the plate meter should be left in position 3 during operation. The other positions of this switch are for use by the serviceman in checking the equipment.

The small toggle switch marked OFF-ON is used to apply power to the radio receiver. When this switch is turned on, a small motor generator inside the cabinet is started, supplying power to the tubes in the radio receiver. The small red panel light on the radio receiver will glow when this switch is turned on. The green pilot light on the transmitter panel indicates when the radio-transmitter motor generator is operating. This pilot light will glow only when the telephone handset is lifted from its switch hook. In other words, when your equipment is "standing by" to receive calls, the radio receiver only needs to be on as indicated by the red pilot light. When you lift the handset to make a call or to answer an incoming call, then the green pilot light on the transmitter will automatically shut down the transmitter and extinguish the green pilot light.

The radio receiver in the center section of the cabinet is provided with a loud-speaker so that you may listen for incoming calls. In addition, the radio receiver is designed with an automatic ringing device (mounted inside the receiver) so that harbor stations may "dial" your ringer number which will actuate a bell inside the cabinet. The automatic ringer enables you to "stand by" to receive calls from the harbor stations

without listening for signals through the loud-speaker. However, it is necessary to use the loud-speaker to receive calls from other vessels because automatic ringing may be obtained only through the harbor telephone stations.

The radio receiver is provided with a 10-position frequency switch marked RECR so that you may set the receiver for the correct frequency for incoming signals. A control marked VOLUME, mounted below the name plate on the receiver panel, is provided so that you may adjust the volume of sound from the loud-speaker or from the handset. If it is desired to cut off the loud-speaker completely so that calls from harbor stations may be made through the automatic ringer, the VOLUME control pointer should be turned to the extreme clockwise position, so that the pointer is over the position marked RINGER ONLY.

The switch in the lower center section of the receiver panel which is marked VOLUME SWITCH is used only for installations where a second extension handset is supplied with the installation. The purpose of this volume switch is to transfer the volume-control circuits either to the handset near the cabinet or to the extension handset. If your installation is provided with an extension handset, and you are using the local handset adjacent to the cabinet, you should throw the volume switch either to the right or left position until you observe that the volume control on the panel operates to regulate the signal coming from the loud-speaker. The operation of the volume switch may be better understood when it is realized that the extension handset is provided with a similar switch. If someone has been using the extension handset, he will have placed his volume switch in the proper position to obtain control of volume. Then if you wish to use the local handset, you will throw your volume switch on the panel either to the right or left in order to reconnect in the circuit the volume control on the receiver panel. In the same manner, if the last person using the equipment employed the local handset and it is desired to use the extension handset, one simply throws the extension volume switch to the right or left in order to secure control with the extension volume control.

For installations where a second handset is required, there is furnished an extension handset and a remote-control unit which may be installed in any convenient location aboard the vessel. When the extension or remote equipment is used, it is necessary, of course, for the radio transmitter and receiver to be previously adjusted to the desired transmitting and receiving frequencies. The remote-control unit is designed with a mounting for the handset and switch hook and also contains a loud-speaker, a bell for automatic ringing, a volume control, and a volume-switch control. The operation of these controls is similar to the same controls on the front panel of the radiotelephone. If an incoming call is heard in the loud-speaker or from the bell of the remote-control unit,

it is simply necessary to remove the handset from the switch hook to carry on two-way communication. As previously explained, the volume switch should be thrown either to the right or left positions, that position being used which enables you to adjust the incoming signal with the volume control.

b. Operating Procedure. 1. **IMPORTANT:** Always make certain that the switches marked TRANS and RECR are in the correct positions for the transmitting and receiving frequencies that you must use to communicate with a desired station. Failure to do this may not only result in interference with other stations, but may also cause fuses to blow in the radiotelephone equipment. This point is emphasized because of the fact that, although a total of 10 frequencies may be provided, in the average installation you may not require all 10 frequencies and, accordingly, some of the switch positions will not be provided with the appropriate quartz crystals. Operation of the transmitter with the TRANS switch in a position for which no crystal is supplied may result in blown fuses. The correct positions for which your radiotelephone is tuned are marked in red on the switch dials and also on the instruction plate on the receiver panel.

2. Turn on-off switch to ON. Red light will indicate. Place handset switch in PRESS-TALK position. Place current switch in position 3.

3. After the tubes in the receiver have warmed up, requiring approximately 15 sec., adjust volume control and listen to loud-speaker to insure that some other station is not using the frequency you have selected.

4. You are now ready to adjust the transmitter. Remove handset from the hook, causing green light to indicate. After the transmitter tubes have warmed up (15 sec.), press the push button on the handset and rotate the upper large knob marked ADJUST FOR MAXIMUM ANTENNA CURRENT until you obtain a maximum reading of antenna current on the meter. The plate-current reading on the other meter will also increase when the antenna current is adjusted to its maximum value. You are now ready to carry on two-way communication with the harbor station or with another ship, depending, of course, on the positions for which you have adjusted the switches marked TRANS and RECR. For example, if you were to communicate with the New York harbor station, the TRANS switch and the RECR switch would be placed in position 8. If you expect to receive calls from the New York harbor station, it is a good plan to leave your transmitter adjusted for the New York harbor station frequency, corresponding to position 8 of the two switches as previously explained. On the other hand, if you expect to call another ship or receive calls from another ship, it is necessary to use the intership frequency of 2,738 kilocycles, corresponding to switch position 10. When changing the antenna tuning from a harbor station to intership, it is necessary to rotate the large tuning knob several times until maximum antenna current is obtained. When changing from one harbor station frequency to that of another harbor station, the antenna-tuning knob requires rotation only a few times. After correct adjustments have been made as indicated, you are now ready to call the other station or to receive calls, remembering to press the push button while you are talking and to release this button when you expect to receive. If it is not desired to use the push button, you may place the hand-set switch to the automatic position and obtain automatic send-receive operation as previously explained. When using automatic operation, it is necessary to speak into the microphone with a steady voice for best results. It will be observed that when using the push button (press-talk condition), the incoming speech is heard from the loud-speaker. Under automatic conditions, the incoming speech will be heard in the handset instead of in the loud-speaker.

5. When calling harbor stations or other ships, it is recommended that you repeat your call two or three times followed by your own call letters and the name of your vessel, and then listen for a reply.

6. At the end of conversation, announce that you are "signing off" and replace the handset firmly on the switch hook.

7. If you expect to receive a call from another vessel or from a harbor station by means of the loud-speaker, you would adjust the volume control up to the point where atmospheric noise from the loud-speaker is not annoying. If you expect to receive calls from a harbor station through the automatic ringer, and do not wish to hear the signals through the loud-speaker, turn the volume control pointer to the position marked **RINGER ONLY**.

c. Talking from One Boat to Another.—The frequency of 2,738 kilocycles (TRANS and RECR switches both in position 10) is assigned by the FCC for intership communication so that two-way conversation may be carried on between boats equipped with radiotelephones. In general, owners using this frequency make prearranged schedules with one another so that each party may have his loud-speaker turned on at the correct time. The automatic ringer cannot be used to receive calls from one boat to another, and it is necessary, therefore, to use loud-speaker calling.

d. Distress Calls.—In case of distress, when it is desired to communicate with the shore station immediately, the distress signal **MAYDAY** should be used. This word should be spoken clearly into the microphone three times or more, followed by the call letters and name of the boat and other necessary information as to the nature of the distress. After the **MAYDAY** call and other information have been transmitted, listen for acknowledgment from the shore station.

The United States Coast Guard maintains a listening watch on the frequency of 2,670 kilocycles (switch position 9) at various points along the coasts and Great Lakes. If the radio equipment is supplied with crystals for this frequency, emergency communication *in cases of actual distress* may be carried on with the Coast Guard. This frequency *must not* be used for any communications other than those involving actual distress or safety of life.

e. Component Parts.—A complete ET-8012-B installation requires the following major units:

- 1 transmitter-receiver assembly.
- 1 type E-3 handset (push button in handle).
- 1 type G-3 switch hook assembly.
- 1 type 20-A line filter (contains line switch and fuse).
- 1 AVA-10 quartz crystal with holder for each transmitting frequency required.
- 1 AVA-10 quartz crystal with holder for each receiving frequency required.
- 1 set of radiotrons for the transmitter consisting of five 807, two 809, and three 6A6.
- 1 set of radiotrons for the receiver consisting of four 6L7, one 6R7, two 6C5, one 6V6, one 5W4.
- 1 set of spare radiotrons for entire equipment consisting of one 6L7, one 6R7, one 6C5, one 6V6, one 5W4, one 807, one 809, one 6A6.
- 2 spare pilot lights, 6.3-volt Mazda 46 blue bead.
- 1 set of spare fuses:

110-volt Installations

- Six 1-amp. glass fuses.
- Six 3-amp. glass fuses.
- Six 10-amp. links.
- Six 30-amp. links.
- Six high-voltage fuses.

32-volt Installations

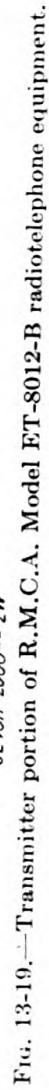
- Six 1-amp. glass fuses.
- Six 10-amp. glass fuses.
- Six 15-amp. links.
- Six 30-amp. links.
- Six high-voltage fuses.

- 1 antenna system and lead-in insulator.
- 1 instruction book.
- 1 remote control unit with type E-3 handset and type G-3 switch hook assembly (furnished only when ordered as an additional item).

f. Description of Transmitter.—Referring to the diagram, Fig. 13-19, the radio-frequency portion of the transmitter uses two stages consisting of an RCA 807 crystal oscillator and four RCA 807's in parallel for the power amplifier. The proper crystal and power-amplifier tank inductance taps are selected by a two-gang 10-position switch controlled from the front of the panel. This is the switch marked TRANS. The antenna is coupled by means of common capacity which will be described in detail. The antenna is resonated by means of a rotating coil controlled by the large knob near the center of the transmitter panel. A fast-acting relay transfers the antenna from the receiver to the transmitter and in addition opens the loud-speaker or handset receiver circuit. This relay may be actuated, as previously described, by either one of two methods. If press-talk operation is selected by the handset switch, the relay is energized by direct current taken from a tap on the bleeder network across the 500-volt supply. If the handset switch is on AUTOMATIC, the presence of audio frequency in the microphone automatically closes the relay through the use of a special vodas tube the action of which will soon be described.

Referring again to the diagram, the microphone voltage is applied to the speech-amplifier stage which uses one 6A6 double triode. This tube, in turn, excites the grids of the 6A6 driver stage which operates as a class *B* amplifier. The driver stage not only excites the grids of the two 809 tubes which operate class *B*, but also applies audio-frequency voltage to the grids of the Vodas 6A6 tube which acts as a full-wave rectifier producing direct current to energize the send-receive relay. A sensitivity control which consists of a 50,000-ohm variable resistance is provided to desensitize the automatic action in case room noises are excessive. This control should be set by the installation man only if he considers it to be necessary. The equipment, as received from the factory, will have the sensitivity control set at maximum resistance so that it acts as a 50,000-ohm shunt on the relay coil. If it is found that room noises are sufficient to energize the send-receive relay, then the sensitivity control should be turned clockwise just enough to keep room noises from energizing the relay. It will be found that push-button operation will be more satisfactory if the noise in the room is great enough to cause the send-receive relay to close without speech.

g. Description of Receiver.—The receiver, as shown in Fig. 13-20, consists of a nine-tube superheterodyne circuit, using a 6L7 radio-frequency amplifier, a 6L7 mixer, two stages of 6L7 intermediate-frequency amplifiers, a 6C5 crystal-controlled radio-frequency oscillator, a 6R7 detector



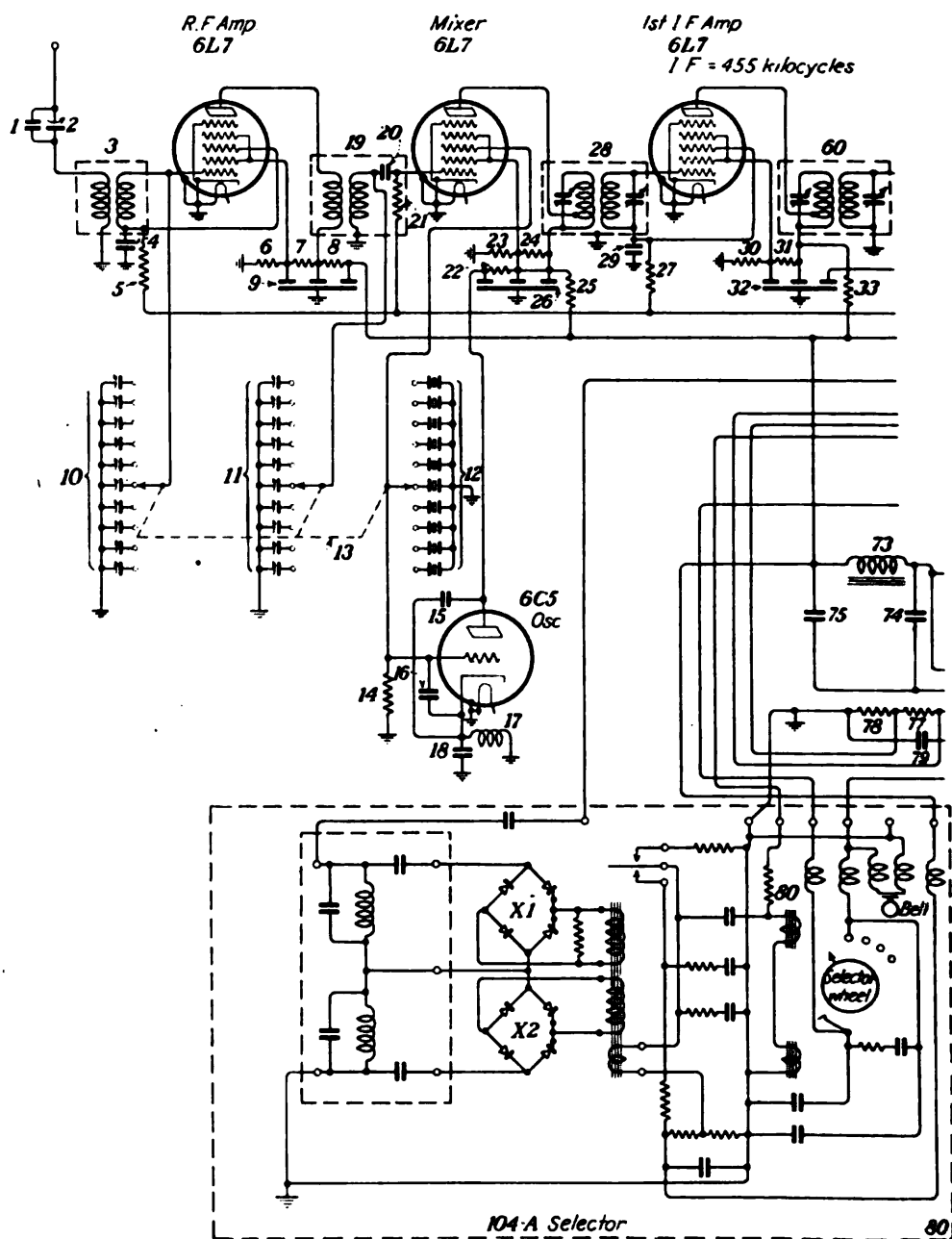
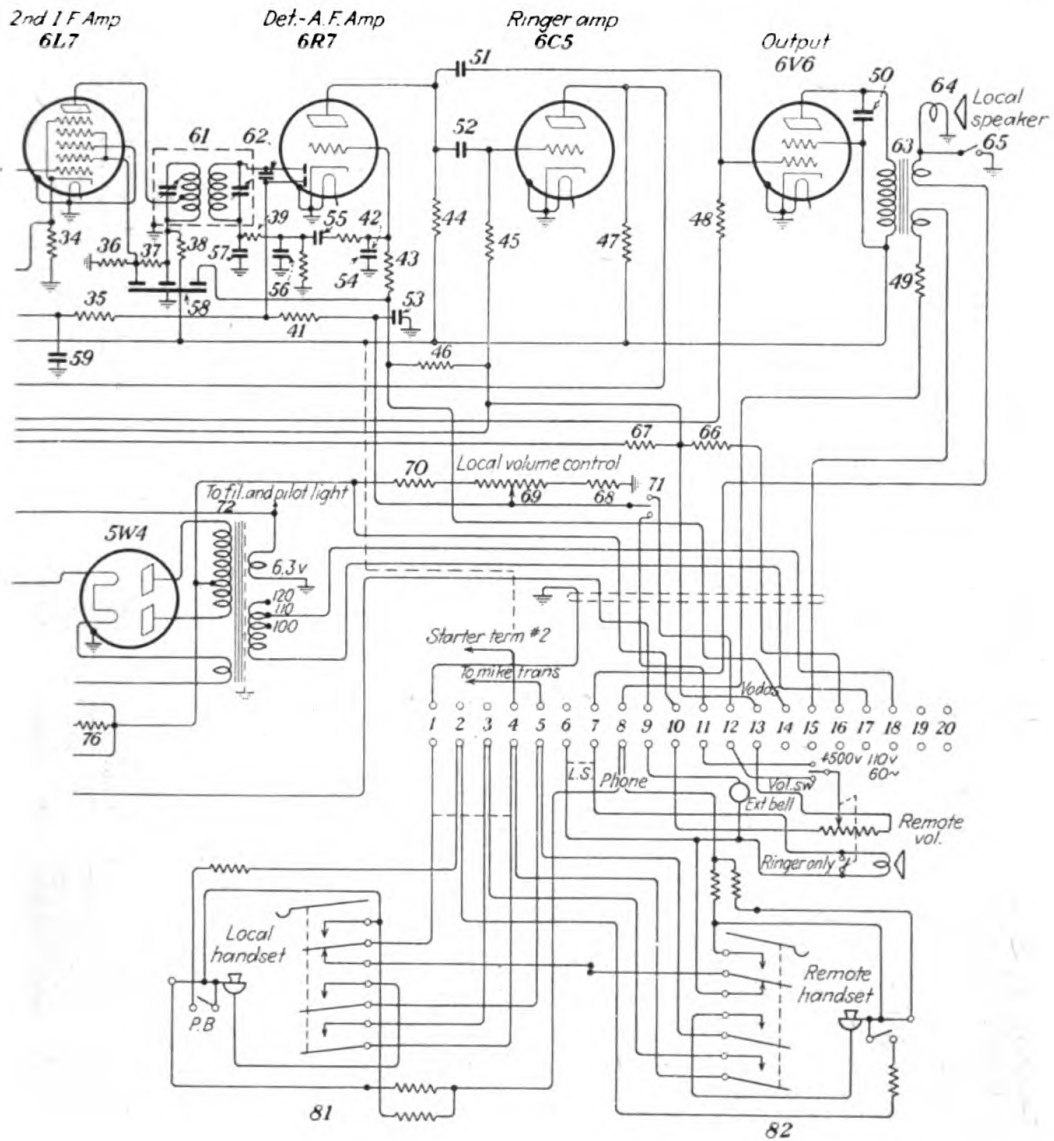


FIG. 13-20.—Receiver portion of R.M.C.A.



Model ET-8012-B radiotelephone equipment.

and audio-frequency amplifier, a 6C5 audio-frequency amplifier for operating the automatic ringer, a 6V6 audio-frequency amplifier for the loud-speaker or the handset, whichever is used, and a 5W4 rectifier tube. The receiver has the automatic ringer built in so that no additional wiring is necessary. Since the numbers used on the automatic ringer code wheel are assigned by the local telephone companies, the automatic ringer will have to be set by the installation man. Whenever possible, the selector code wheel will be set at the factory if the "telephone number" of the installation is known before shipment.

13.9. A Complete Ship-radio Station.—The layout of a complete ship station is shown in the block diagram (Fig. 13-21), in which the relation of

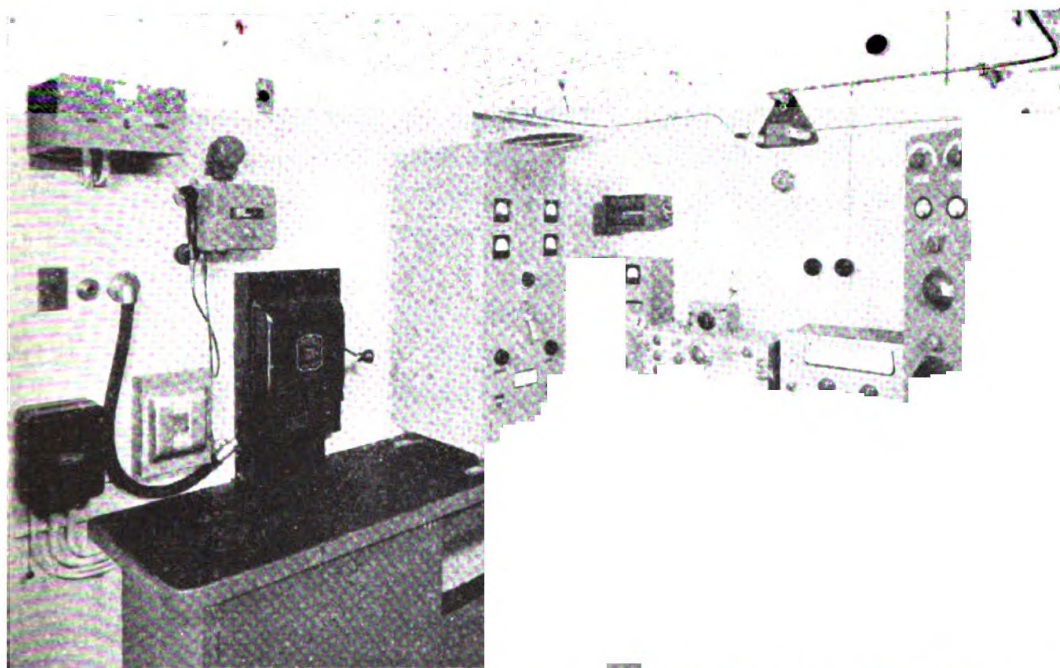


FIG. 13-22.—Complete radio installation on ocean-going vessel. (Courtesy of R.M.C.A.)

One piece of equipment to another in the radio system is clearly shown. This arrangement is only general in nature, and the actual location of each piece of equipment depends upon the physical dimensions of the radio room. The arrangement here shown is, however, typical on American vessels, although somewhat different schemes are employed on many foreign ships.

Modern radio direction finders are a part of the radio equipment of most of the larger vessels. This equipment is usually located in the pilot house or chart room adjacent to the navigating bridge and is, therefore, not shown in this block diagram. The radio operator is, however, usually responsible for the maintenance of the radio direction finder, although it is operated by the navigator himself or one of his assistants.

A photograph of a modern ship installation as illustrated previously by the block diagram is shown as Fig. 13-22.

13.10. Transmitter Care and Maintenance.—On a shipboard installation the transmitter may in time be covered in part by salt spray and moisture which may allow high-voltage creepage along the panel or other insulation thus affected, resulting finally in a complete breakdown. To avoid such trouble the operator should go over all units and accessible parts daily with a clean dry rag.

All moving parts, except commutators and micarta bearings of tuning variometers, should be oiled to insure smooth operation. If radiation is low, examine the set for loose or broken connections. This may also cause excessive heating of the vacuum tubes. See that all grid leaks fit snugly in their clips.

All relays should be examined frequently to see that the contacts make and break properly. If the contacts are badly pitted, they may be filed down or replaced with new contacts.

See that all tubes are functioning properly and that there is no blue flashing or change in filament temperature when the key is pressed. If this occurs new tubes may be tried throughout, but the old tubes should be immediately replaced if the new tubes do not remedy the trouble.

There should be no sparking about the set when the key is pressed.

Examine automatic motor starter monthly and see that contacts are kept clean and smooth; file down or replace when necessary.

The care and operation of the motor generator are completely discussed in Chap. 17.

Troubles, their causes and remedies, are covered in Table XIII A. Care of vacuum tubes is explained on pages 437, 438, 446, 447.

The contact surfaces of the rotary coils used in certain types of short-wave transmitters in the high-frequency tuning system should be cleaned by holding a piece of fine sandpaper against the outside surface and rotating the coil. Oil should never be used on the coil windings.

Antenna systems should be inspected weekly to make sure antenna wire or wires and leadins are held tightly in position. Clean deck and lead-in insulators weekly with a dry cloth. If antenna insulators become covered with carbon, and cleaning is ineffective, they must be replaced.

13.11. Transmitter Troubles.—The most satisfactory formula for preparedness against apparatus failure, in general, is to know your circuits. It is impractical to supply written directions for finding and curing all the different troubles which may occur in a radio transmitter; the best that can be done is to list some of the most common troubles with their causes and remedies. Such a table follows, and the student or operator is urged to give it careful study.

When trouble occurs, go about finding the cause in a systematic manner. Inspect all the meter readings to localize the trouble, which is usually in one portion of the apparatus such as the power supply, the rectifier or motor generator, the oscillator, the amplifier or the antenna

TABLE XIII A.—TROUBLES IN VACUUM-TUBE TRANSMITTERS

Troubles	Probable causes	Probable remedies
1. Motor generator does not start	Open switch or fuse. Line voltage "off" or too low. If key relay works, line voltage is "on"	Close switches, or replace fuses. Close any open overload circuit breakers
2. Start contactor closes, but motor generator does not start	Burned-out starting resistor or open connection between starter and motor. Frozen bearing	Try shorting out burned-out sections of starting resistance. If fuses continue to blow, use water rheostat
3. Tube filaments do not light	Assuming generator is all right, look for blown fuse caused by filament shorted. Loose connection on, or defective, filament transformer, panel, or socket. Defective brush on motor slip rings. Defective tube. Open in filament rheostat	Test filament in each tube by continuity test with voltmeter. Open indicated by no reading; short indicated by full reading. Replace blown fuses or tighten loose connections. Replace brush if necessary. Repair rheostat or transformer (17, 18)
4. No radiation, tubes heat only to dull red (see also 23)	Antenna circuit out of tune. Grounded or open antenna circuit. Open or loose connections in r.-f. circuit in set	Tune set for maximum radiation. Shift to another wave band. Fix loose connections
5. Tubes heat badly when key is up	Improper blocking bias caused by defective resistor or open or loose connection. Soft amplifier tube may partly short bias voltage. Soft tube will probably flash blue and overheat	Fix connections or repair resistor. If a small section of resistor is burned out, defective part may be jumped with one or more 60-watt tungsten lamps. Replace defective tube
6. Tubes heat badly when key is pressed	Oscillator tube defective or oscillator circuit not oscillating because of loose connections. Defective grid leak	Remove all but oscillator tube. If tube gets too hot, circuit or tube is defective. Fix circuit or replace tube (see 19 and 20).
7. Amplifier tubes heat excessively when key is down and antenna circuit is in tune	Defective coupling transformer or insufficient number of plate turns in use	Fix coupling transformer or increase plate turns
8. Audio oscillator does not operate	Loose connections to switches, transformer, or condenser. Defective condenser or tube	● Tighten all connections and replace tube
9. Extremely high plate current when key is pressed	Shorted grid leak somewhere possibly. Excessive voltage on filament or plate. Oscillator not operating	Fix or replace grid leak which is defective. Test with continuity test with voltmeter. Full reading indicates short circuit. Adjust voltages. Fix oscillator
10. Chopper motor does not start	Loose or open connections to motor. Poor brushes. No oil in bearings	Fix connections or close circuit. Replace brushes. Oil bearings
11. Insulation breakdown	Excessive potential. Salt deposit from atmosphere. Dirt on surface. Carbon on surface	Replace insulation if possible and necessary; clean off burned section; cut away burned section. Cut winding, and remove sufficient turns to clear; then jump removed section. If switches, remove them from the circuit and complete circuit with temporary jumper
12. Master-oscillator plate choke burned out	Defective choke, or too much current	Remove burned-out turns or replace by spare or by grid choke. Close grid circuit with jumper. Operate set on reduced power
13. Plate- or grid-blocking condenser shorting	Excessive current surges, or defective condenser	Remove condenser and substitute the tank condenser from another wave-band circuit or replace with an equivalent condenser from some other apparatus

TABLE XIII A.—TROUBLES IN VACUUM-TUBE TRANSMITTERS.—(Continued)

Troubles	Probable causes	Probable remedies
14. Plate voltmeter not operating	Loose connections or defective meter	Maintain generator field rheostat at usual position, and watch tubes to see that they operate at normal temperature
15. Plate ammeter not operating	Loose connections or defective meter	Insert a 150-watt lamp in place of meter, and do not allow it to exceed full brilliancy when it replaces 0-5-amp. meter
16. Antenna ammeter inoperative	Overloaded or defective meter	Adjust set in accordance with tuning-record card, and observe plate ammeter for final resonance
17. Filament transformer burned out	Overloaded or defective transformer or circuit	Connect a sufficient number of heavy-duty storage cells in series to give required filament voltage and connect direct to filament bus bars with wire heavy enough to carry the filament-current load. Rheostat should be in circuit, but cut out if not necessary
18. Filament rheostat burned out	Short circuit in filament circuit; rheostat not heavy enough, or too old and worn out	Use lead cells as described above, but test total voltage with voltmeter. Do not exceed rated filament voltage of tubes. Cut rheostat out of the circuit
19. Grid leak open in master-oscillator circuit	Subject to overload or defective	The grid leak in an oscillator circuit may be replaced by a resistance of 4,000-10,000 ohms. A column of water, 12 in. long, in a rubber hose plugged at each end and having wire electrodes will be satisfactory. If the resistance is too high, add a little salt or washing soda
20. Grid leak open in power amplifier	Has been subjected to an overload or is defective	Substitute depends on number of tubes used; a 40-watt tungsten lamp equals 370 ohms; a 60-watt lamp equals 220 ohms. One or more lamps may be used in series, in parallel, or in series-parallel in an emergency depending on the tubes used
21. Tank condenser shorted or overheating	Overloaded or strained by excessive surges	Replace defective condenser by similar one taken from another tank circuit or by spare condenser
22. Failure to oscillate	1. Fuses blown 2. High-potential plate supply circuit open (burned-out radio-frequency choke, poor plate connection on the tube, burned-out generator-filter condenser and choke, improperly fitted brushes on the generator commutator, broken leads) 3. Oscillatory circuits not adjusted properly. Improper values of plate and grid inductances or capacities 4. Burned-out grid leak or grid choke	1. Replace fuse 2. Close plate supply 3. Tune oscillator 4. Replace defective leak or choke

TABLE XIII A.—TROUBLES IN VACUUM-TUBE TRANSMITTERS.—(Continued)

Troubles	Probable causes	Probable remedies
	5. Plate- or grid-blocking condenser open or shorted (the latter may produce serious overheating of the tube) 6. Plate potential too low 7. Filament potential too low 8. Aerial or ground circuit open 9. Transmitter improperly tuned to resonance with the radiating system 10. Filament deactivated 11. Sagging filament touching the grid 12. Loose, dirty, or corroded connections, especially in the oscillatory circuit 13. Poor tube-socket connections	5. Replace defective condenser 6. Increase plate potential 7. Increase filament voltage 8. Inspect and repair antenna and ground 9. Tune amplifier and antenna system 10. Replace tube or reactivate by operating filament at normal temperature with plate power "off" for 10 min. or longer 11. Place tube in various positions, if possible, or replace tube 12. Fix poor connections 13. Tighten spring action in tube sockets and remove corrosion with fine sandpaper
No indication of radiation (see also 4)	1. Tube not oscillating 2. Defective antenna ammeter 3. Defective antenna insulation 4. Circuits not in resonance 5. Poor connections on the antenna 6. Improper coupling	1. See 22 2. See 16 3. See 11 4. Tune circuits to resonance 5. Solder all joints 6. Adjust coupling
Low radiation	Dirty or leaky insulators Circuits out of tune Improper coupling Improper voltages See causes and remedies under 23 some of which may cause low radiation. Defective crystal, oscillator tube, or interstage transformer Abnormally high screen-grid current	Clean or replace insulators Adjust circuits Adjust coupling Adjust voltages See 35; replace tube, or transformer
No plate voltage	Open relay; open door switch; open generator field rheostat; defective voltmeter; blown fuses; poor brushes on generator; no generator field excitation	Close relay and switches; repair rheostat; replace fuses after rectifying cause of blowout; clean commutator, or fix or replace brushes. Close excitation circuit on generator
No plate current	Open overload relay; poor plate-terminal connection on tubes; no voltage, see 25; defective or open plate ammeter; defective tube; grounded high-voltage line	Close relays; fix any loose connections; apply remedies given under 25; See 16; replace tube; clear high-voltage line of grounds, if circuit so demands
No grid current on oscillator	Plate voltage too low; poor connection on tube; poor keying contacts; open grid leak	Raise plate voltage; tighten all connections; adjust and clean keying contacts; replace grid leak
Too high grid current on oscillator	Disconnected or grounded antenna; antenna circuit out of tune insufficient load on oscillator	Examine antenna and lead-in insulator, clean or repair tune antenna circuit; tighten coupling to antenna

TABLE XIII A.—TROUBLES IN VACUUM-TUBE TRANSMITTERS.—(Continued)

Troubles	Probable causes	Probable remedies
29. Keying relay inoperative	No line voltage; wave-change switches do not line up properly; contacts stuck together; open resistor in circuit; relay coil burned out or open	Close line circuit; adjust wave-change switches; clean contacts with fine sandpaper; replace resistor; repair magnet coil
30. Failure of chopper motor to start	No line voltage due to open switch or fuse; motor needs oil; commutator dirty, or brushes defective	Apply line voltage; oil motor; clean commutator and brushes; replace brushes
31. Ragged ICW signals	Dirty commutator on chopper; poor contact by brushes to chopper commutator	Clean commutator with No. 00 sandpaper. Fix brushes, and adjust pressure on commutator
32. Unsteady short-wave signals	Swinging antenna; loose high-frequency connections; too-close antenna coupling; erratic atmospheric conditions; wrong frequency being used	Fix any loose connections; adjust coupling; other causes are usually beyond control of operator if right frequency is being used
33. White deposit inside tube	Air leak; deposit shows up when voltage is applied to filament	Replace tube
34. Deviation of frequency	On crystal-controlled sets, failure of temperature-control equipment	Inspect thermostat; replace, if necessary
35. Failure of crystal oscillator to oscillate	Defective crystal caused by chipping, or dirt in holder; defective tube; open circuit	Clean crystal and electrodes using carbon tetrachloride and lens paper or other lintless material. Do not touch crystal surfaces after cleaning. Set upper electrode firmly on crystal; replace tube; look for open circuit
36. Too high r.-f. output	Antenna adjustment incorrect Incorrect or reversed screen voltage	Adjust antenna circuit and coupling Adjust screen voltage to proper value
37. One parallel tube heats badly	In amplifier circuits using two tubes in parallel, the trouble is due to the tubes not dividing the load	Check wiring or interchange tubes until two are found which will divide the load
38. Filament voltage not up to normal	Ship's line voltage below normal. Wrong primary tap on filament transformer connected to the line	Check the line voltage. If it is much lower than normal, change tap (if provided) on filament transformer to next lower tap. If, too high, change to next higher tap. Alternative: raise ship's line voltage
39. Plate voltage below normal	Generator field may be open Defective rectifier tube Filter or by-pass condenser or high-voltage wiring defective Plate generator field rheostat may be burned out	Close door on overload relay. See that line switch is ON. Replace plate power fuse which should blow and replace tube Replace condenser or fix wiring Repair or replace rheostat
40. Excess oscillator plate current	Defective oscillator tube	Examine grid bars. Look for blue glow. Replace tube.
41. Excess amplifier grid current	Antenna detuned Defective amplifier tube	Resonate antenna circuit. Replace tube
42. Excess amplifier plate current	Too little coupling to antenna. Defective amplifier tube. Too few turns in amplifier plate coupling transformer primary	Adjust coupling; replace tube; increase number of turns in amplifier plate coupling transformer

TABLE XIII.A.—TROUBLES IN VACUUM-TUBE TRANSMITTERS.—(Continued)

Troubles	Probable causes	Probable remedies
43. Amplifier plate current too low	Antenna detuned. Too many turns in primary of amplifier plate coupling transformer. Defective tube	Resonate antenna circuit. Decrease primary turns in amplifier plate coupling transformer. Replace tube
44. Antenna current low	Antenna detuned. High resistance contact to antenna. Partial insulation breakdown in antenna loading coil. Wrong number of turns in amplifier plate coupling transformer secondary	Resonate antenna circuit. Remove any contacts to antenna. Scrape away charred portion of insulation, and reduce power to safe limit. Adjust number of turns in plate coupling transformer
45. No antenna current	Antenna open-circuited or grounded. Tap leads to loading coil may be grounded or crossed	Fix antenna circuit or taps on loading coil

system. Compare present performance with normal performance; this should tell the operator a great deal.

Continuity tests can be made with a high-resistance voltmeter and, in many instances, a battery. On speech-amplifying equipment, output can be checked by listening across the secondary output impedance of the output transformer with a pair of high-resistance headphones in series with a blocking condenser of 1 or 2 mf. capacity.

If *C* batteries are used, they should be checked occasionally and replaced when their voltage has fallen 15 per cent.

Radio-frequency output voltage can be checked by means of a small neon light. In high-power stages, the presence of radio-frequency energy can be determined by touching the high-potential end of the tank with a small coil of two or three turns of bare copper wire on the end of an insulating stick or handle. Radio-frequency potentials of 200 to 300 volts or more will cause arcing to the coil.

When other remedies fail, it is always advisable to change tubes, as spurious conditions often exist in an apparently good tube.

13.12. Ship Antennas.—The usual antenna system used with marine transmitters in the intermediate- and high-frequency bands is the Marconi or grounded radiator, in contrast to the Hertz or ungrounded radiator. The Marconi radiator is resonant to any odd multiple of a quarter-wave length. This means that it operates normally as a quarter-wave antenna, or it may be operated on any odd harmonic of this wave, namely, as a three-fourth- or five-fourth-wave antenna. Owing to physical limitations, however, the antenna used is generally a quarter-wave antenna. The quarter-wave transmitting antenna may be efficiently loaded up to about twice its resonant wave length by the insertion of antenna inductance, or it may be shortened down to about three-fourth of its resonant wave length by the use of a series condenser.

In the practical design of a Marconi radiator, allowance must be made for the coupling inductance necessary in the transmitter, which

means that the resonant wave length of the wire from the remote end of the antenna to the antenna-terminal connection on the transmitter should be about 25 per cent lower than the lowest working wave length.

For example, to work on a minimum wave length of 560 meters, which is the low end of the marine band, a quarter-wave antenna could be 140 less 35 meters, or approximately 105 meters long. Converted to feet this equals 344.5 ft. Allowing 50 ft. for the leadin, this leaves an optimum length for the flat top of approximately 300 ft. The length of the leadin and flat top combined could be reduced to a minimum of approximately 150 ft. on small vessels, and good intermediate-frequency-operation would still be possible.

On large vessels the natural frequency of particularly long flat tops may be reduced by connecting the lead-in wire to the center of the flat top, thereby using the antenna as a T type.

The insulation of the ship antenna must be adequate, owing to the tendency of smoke and salt air to form a conducting surface over the insulator. The end or ends most remote from the transmitter are where the highest voltage strain exists and must be well insulated.

13.13. Coast Stations.—Transmitters in coast stations are for the most part especially built for the particular service they are expected to perform. For some communication purposes, conventional ship transmitters operated from three-phase power lines are used, whereas for other purposes a special model is built for the work to be performed. Coast stations may be called on to communicate over very long distances by high-frequency and low-frequency emissions. For long-distance work, A1 emission is used exclusively; whereas for short-distance work, both A1 and A2 emission are used.

Long-distance communication to vessels in the North and South Atlantic, the Red Sea, Mediterranean, and Indian Ocean can be effected through the Radiomarine Corporation stations at Chatham, Mass. (WCC), and Tuckerton, N. J. (WSC), and by way of the station of the Mackay System at Sayville, N. Y. (WSL).

On the West Coast of the United States, the Radiomarine Corporation station at Bolinas, Calif. (KPH), and the Mackay System station near Palo Alto, Calif. (KFS), handle traffic from ships in the North and South Pacific Oceans and the adjoining seas of Okhotsk, Japan, South China, and Tasman seas.

It is interesting to note that the areas covered by the East and West Coast American stations overlap somewhere in the Indian Ocean, or thereabouts, and thus these stations taken together cover the entire world. Their service is truly world-wide.

Numerous other stations are provided on both coasts for short-distance communication.

The transmitting equipment at a typical coast station is that provided at the Radiomarine Corporation station at Tuckerton, N. J. (WSC), which is tabulated below, eight transmitters being provided at the time the information was made available. The frequencies given are subject to change.

Approximate wave length, meters	Frequency, kilocycles	Power
17.79	16,860	1 kw.
23.66	12,675	40 kw.
26.84	11,175	200 watts
35.60	8,430	40 kw.
47.24	6,350	200 watts
47.31	6,340	1 kw.
600 and 649.3	500 and 462	5 kw.
2,255 and 2,400	133 and 125	3 kw.

In order that duplex operation may take place, the transmitters at high-powered stations are located at some distance from the receiving station. For example, at Chatham, Mass. (WCC), the transmitters are located at Marian, Mass., a distance of 50 miles, whereas at Tuckerton, N. J. (WSC), the transmitters are located 5 miles from the receiving station. In this way, during periods of heavy traffic, arrangements can be made to provide as many operating channels for simultaneous operation as may be necessary to handle the traffic expeditiously.

At lower powered coast stations, as for example Savannah, Ga. (WSV), both transmitters and receivers are located under one roof and are generally of the type found aboard ship.

CHAPTER 14

MARINE RADIO RECEIVERS

The radio receiver constitutes one half of the complete radio system. In designing either a transmitter or receiver, the complete system must be considered. Hence, in receiver design full account must be taken of the type of transmitter with which the receiver is expected to work. Whereas some receivers are designed as general-purpose receivers, most receivers are designed with a particular service in mind. This is especially true of the marine radio receiver.

14.1. Marine receivers are especially designed for use aboard ship and incorporate features necessary for this service. They are primarily designed to receive radio-telegraphic signals and are very selective and sensitive. They cover the frequency bands allotted to marine work, and for this reason may also be used in shore stations which are the land terminals of the marine radio-communication systems.

Owing to the various conditions of climate and weather in which marine receivers are used, and to reduce receiver failures, it is necessary that they be ruggedly built. Simple circuits are favored so that repairs can be made, when necessary, by the operator at sea, away from service stations.

Long before the advent of broadcasting, marine receivers had reached a high state of development. The rapid perfection of broadcast receivers was due, in no small measure, to the experience gained by radio science in the building of efficient marine receivers. While improvements have been made in marine receivers since the beginning of broadcasting, these improvements are due mostly to the new types of vacuum tubes made available for broadcast receivers which have also lent themselves to the improvement of marine receivers. Certain special features, such as volume control and alternating-current operation, have been borrowed from broadcast-receiver design, but, on the whole, marine receivers constitute a class by themselves incorporating features which have grown out of the practical use of these receivers aboard ship.

Marine radio receivers are divided into four classes, namely, automatic alarm receivers, direction-finder receivers, emergency receivers, and main receivers. Only the latter two classes will be studied in this chapter. The first two will be studied in later chapters.

Regardless of whether a regenerative detector or a superheterodyne circuit is used in the receiver, it is necessary to produce audio-frequency

beat signals to make the continuous-wave (A1) signals audible in the headphones. This is accomplished by using the regenerative circuit as an autodyne or by using a superheterodyne circuit. If the emitted signal is of the modulated continuous-wave (A2) type, it is not necessary to produce an audio beat frequency at the receiver.

14.2. Audio-amplifier Response Characteristics.—Inasmuch as the marine radio-telegraphic receiver has to respond only to code characters sent or received on a very limited number of specific audio frequencies, and, in fact, as it is designed to be extremely selective in its tuned circuits, the audio transformers used with these receivers have a *peaked* frequency characteristic. They are known as *peaked transformers* and

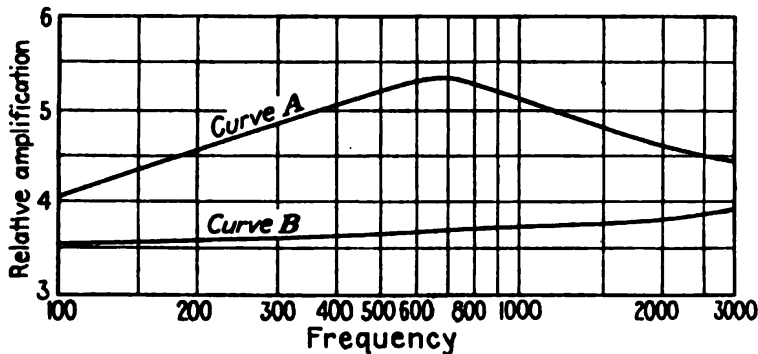


FIG. 14-1.—Characteristics of (a) peaked audio-frequency transformer (b) linear audio-frequency transformer.

give highest relative amplification usually at some frequency between 500 and 1,000 cycles.

The characteristics of a peaked transformer which is peaked for 700 cycles is shown in curve A, Fig. 14-1. The frequency-response characteristic of an audio transformer designed for radio-telephone reception is shown as curve B of the same figure, so that the two types of transformers may be compared. It is readily seen that although the amplification of the transformer represented by curve A is not much different from the curve B transformer at frequencies around 100 and 2,000 cycles, the response of the peaked transformer at 700 cycles is much greater than that of the flat-characteristic transformer. Hence, a marine receiver equipped with ordinary broadcast-receiver types of audio transformers would not be very sensitive nor would it amplify the desired audio frequency and attenuate all other frequencies as does the peaked transformer.

14.3. Audio-amplifier Troubles.—If trouble in the receiver is localized to the audio-frequency amplifier and then further traced to a particular stage of audio amplification, it is quite likely to be due to some constructional or electrical defect in the audio transformer. Perhaps the most common cause of audio-transformer trouble in marine receivers is due to the effect of salt air on the apparatus. In spite of the best pre-

cautions to shield the receiver from climate, salt air is the surrounding medium and may cause trouble. The most common trouble from this source is corroded terminals on the transformer at the point where the soldered connection is made. Fiber insulation is sometimes used in audio transformers, and fiber has a certain amount of acid in it which, when aided by the salt air, may cause a weakening in the insulation of the transformer as a whole.

Another common trouble is that caused by surges due to the opening of the audio circuit in some manner, when full voltage is on. This might happen when shifting headphones from one amplifier stage to another, if automatic filament jacks are not provided to interrupt the current. Such surges cause arcing and may result in complete insulation breakdown and burning off of the fine wire used in the transformer winding; usually a No. 40 B. and S. gage wire is used.

The transformer core may sometimes be grounded causing an electrolysis to take place between the winding (anode) and the core (cathode), resulting finally in a burning out of the transformer winding affected.

Note: The primary and secondary circuits of an audio transformer may be tested by a pair of headphones and a $22\frac{1}{2}$ -volt *B* battery. The headphones and the battery are connected in series and then shunted across the winding to be tested. If the primary circuit is tested, no click will be heard if the winding is open (unless a by-pass condenser is connected across it). If the secondary winding is to be tested, no click will be heard if the winding is open. It is very important when testing the secondary to note carefully the intensity of the click, because the comparatively high resistance of the secondary winding will make the click much feebler than that heard through the primary. High-resistance phones should be used in these tests.

14.4. Power Supplies for Receivers.—Marine receivers are operated from batteries or direct from the ship's line through suitable filters. If batteries are used, filament power is supplied by storage batteries and plate and bias potentials by conventional heavy-duty *B* and *C* batteries of the dry-cell type.

The storage-battery equipment usually consists of two separate batteries so that one may be kept on charge while the other one is being used.

In special instances where alternating-current power is available, vacuum-tube rectifiers are built right into the receiver just as in a broadcast receiver.

An expedient also used to operate a receiver designed for alternating current when only direct current is available is to provide a small 110-volt alternator as the source of receiver power. This alternator may be driven by a small direct-current motor or may be designed as a dynamotor.

Storage batteries and dynamo-electric machinery are treated in detail in later chapters in this book.

14.5. Protective devices to protect the receiver against the damaging effects of near-by transmitters or heavy local atmospheric discharges are provided in the form of a safety gap which is placed across the antenna and ground terminal posts on the receiver. This gap is set to arc over below the breakdown voltage of any insulation in the receiver. Therefore, any high-voltage surges or induced currents which might injure the receiver are automatically conducted directly to the ground. This gap, as pointed out, acts as a lightning arrester when necessary.

When the transmitter is located close to the receiver, as on board ship, an automatic relay is provided which opens the connection from the receiver to the antenna when the transmitting key is pressed and makes the connection again when the key is released, constituting in effect a protective device and a break-in system which enables the operator to listen to signals when his key is up.

14.6. Multiple Reception.—When a number of receivers must be used on one antenna, as is sometimes necessary, receivers utilizing one or more stages of radio-frequency amplification are used. Any local beat frequencies generated in a receiver are blocked by its radio-frequency stages, and all the receivers can be operated without the adjustments of one disturbing the adjustments of the others. Under these conditions a separate receiving antenna is generally used which can be much smaller than the main ship antenna owing to the high amplification of the received signal which is possible when radio-frequency amplifiers are used.

In order to facilitate listening in on the 300- to 550-kilocycle band during silent periods, a stand-by receiver is sometimes provided in addition to the main receiver. Thus, if communication is being carried on using a frequency outside of the 300- to 550-kilocycle band, it is only necessary to switch to the stand-by receiver at the beginning of the silent period and switch back again to the main receiver when the silent period is terminated.

The manner in which the principles outlined thus far are applied to actual receiver design will become apparent from a study of the specific receivers which are described in following sections.

14.7. Common Receiver Troubles Summarized.—The troubles listed below make their remedies apparent, once the trouble is located.

TABLE XIVA.—TROUBLES IN RADIO RECEIVERS

Headphone noises:

1. Loose connections in the circuit or in phone-cord tips.
2. Defective grid leak.
3. Corroded or loose contacts of the tube prongs or sockets.
4. Broken-down grid condenser.
5. Defective tube.
6. Abnormal filament current.
7. Power-line induction.

TABLE XIVA.—TROUBLES IN RADIO RECEIVERS.—(Continued)

Headphone noises:

8. Defective or run-down *A* or *B* batteries.
9. Loose antenna or ground connections.
10. Poorly soldered connections.
11. Excessive plate or filament voltage.
12. Improper regeneration adjustment.

No signals:

1. Open grid circuit in the detector or amplifier circuits.
2. Tuning condenser short-circuited.
3. Poor contacts on inductance switch.
4. Open tuning coils.
5. Improper value of grid-leak resistance.
6. Open plate circuit.
7. Improper filament voltage (weak *A* battery).
8. Deactivated filament or cathode.
9. Broken antenna or ground connections.
10. Defective headphones.
11. Tickler connections reversed (no "C"-type signals can be received).
12. *B* batteries run down.
13. Broken connections (general).
14. Poor telephone plug and jack contacts.
15. Grounded antenna.
16. High-resistance connection due to a poorly soldered joint.
17. *B* battery potential reversed.
18. Short-circuited by-pass condenser.
19. Defective audio transformer due to burned-out or corroded terminal connection.
20. Improper regeneration adjustment.
21. Improper tuning adjustments.
22. Poor rheostat or potentiometer contacts.

Poor signals:

1. Poorly soldered connections.
2. Deactivated filament.
3. Open in radio-frequency transformer winding.
4. Open by-pass condenser.
5. Filament polarity reversed.
6. Improper plate-supply voltage.
7. Run-down *B* battery.
8. Run-down *A* battery.
9. Poor ground connections.
10. Tickler reversed.
11. Poor contact between tube prongs and socket.
12. Antenna circuit open.
13. Poor antenna insulation.
14. Plate potential too high (results in distorted spark signals).
15. Improper tuning adjustments.
16. Improper regeneration adjustment.

14.8. Main Receivers.—The term *main receiver* means a receiver regularly available in a ship station for routine communication and

which ordinarily is energized by a source of power other than the emergency power supply.

1. R.M.C.A. MODEL AR-8503.—This receiver, which is shown in Fig. 14-2, is a compact medium-, low-, and very low frequency receiver, using metal tubes, and designed primarily for marine applications.

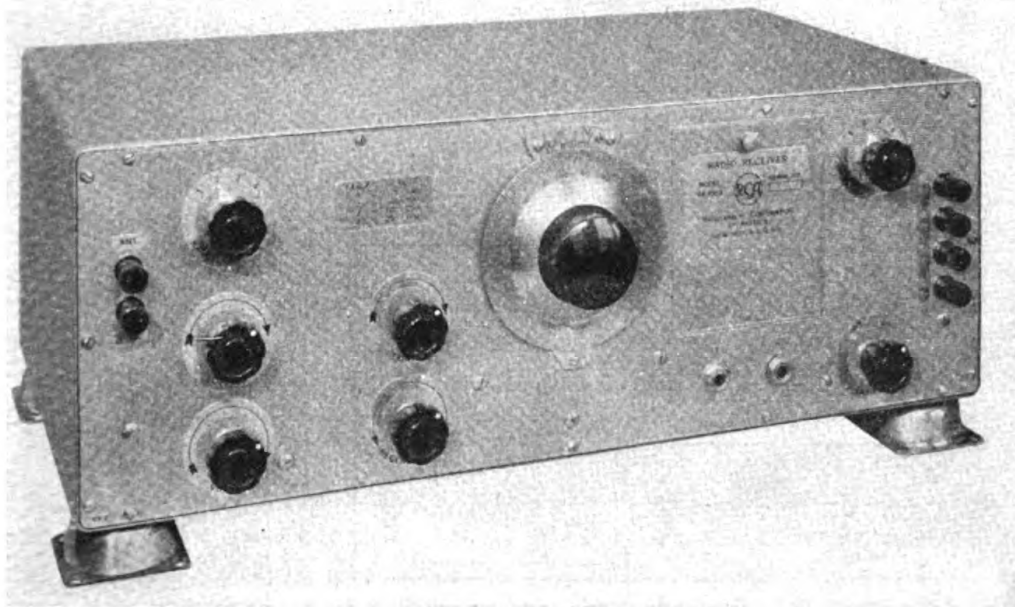


FIG. 14-2.—R.M.C.A. Model AR-8503 marine radio receiver. (Courtesy of R.M.C.A.)

a. General Description.—The receiver covers a continuous frequency range of 15 to 600 kilocycles, divided into four bands, with appropriate selector switches so that any frequency within the range may be quickly selected from the front of the panel. The four frequency ranges in kilocycles are as follows:

Range 1, very low frequency.....	15- 40
Range 2, low frequency.....	40-100
Range 3, low frequency.....	100-250
Range 4, medium frequency.....	250-600

Four metal tubes are used in the receiver as follows:

RCA 6K7.....	R.-F. amplifier
RCA 6K7.....	Regenerative detector
RCA 6K7.....	First audio amplifier
RCA 6F6.....	Second audio amplifier

The power supply required for the receiver consists of a 6-volt *A* battery and a 90-volt *B* battery, with a tap at 22 volts. The *A* battery drain at 6 volts is 2 amp. The *B* battery drain at 90 volts is 8.6 ma. for maximum volume and 5 ma. for minimum volume.

antenna, the radio-frequency-amplifier grid circuit, and the radio-frequency-amplifier plate circuit. A small trimmer condenser adjustable from the front panel is also used in the radio-frequency-amplifier grid circuit. The antenna is coupled to the first or preselector tuned circuit through a small variable condenser. The preselector circuit is coupled to the radio-frequency-amplifier grid circuit inductively, using fixed coupling between the coils. Volume control is obtained by means of a potentiometer, which applies a bias to the cathode of the radio-frequency tube. Regeneration control is obtained by means of a second potentiometer which controls the screen voltage on the regenerative detector. Fixed coupling is used between the amplifier plate coils and the detector tickler coils.

Two selector switches are used: one in the upper left section of the panel, which controls the preselector and radio-frequency grid coils, and one in the upper right section of the panel, which controls the amplifier plate and tickler coils. Separate coils are used throughout for each range so that stable operation is obtained without dead spots or other erratic performance which might result from tapped coils.

The regenerative detector is coupled to the first audio stage through a low-pass filter, and the first audio stage is resistance coupled to the second stage as shown in the diagram. The plate current of the second audio stage is carried through the telephone receivers, and for this reason it is important to use the correct polarity on the telephone cords to prevent demagnetization. With Trimm headphones, the phone plug *tip* should be connected to the *red* tracer. With Western Electric phones, the plug *tip* should be connected to the *green* tracer.

The ON-OFF switch controls the +90, +22, and +6-volt circuits. A special 15-ohm "drying" resistor is mounted on the under side of the chassis to produce a small amount of heat so that the component units are kept dry and free from corrosion. Care should be taken not to operate the receiver with the tube door removed as the entire design has been made to provide complete enclosure of the chassis, which is desirable under marine atmospheric conditions.

c. Operation—Correct procedure in tuning and adjusting the receiver should be carefully understood by the operator. Each range-selector switch should be placed at the proper point for the range desired. The on-off switch should be turned to the ON position, allowing about 15 sec. for the tubes to heat up. The antenna coupling should be turned about 90 degrees clockwise and the volume control about three-quarters clockwise. Regeneration control should be turned about one-half counter-clockwise. The main tuning dial should now be rotated for the desired signal.

After the signal is heard, adjust antenna-coupling and trimmer condensers for maximum and adjust the volume control for the desired signal

intensity. The regeneration control may then be adjusted to improve the selectivity or to produce oscillations for A1 reception. It is emphasized that the volume control should never be used at its maximum position unless very weak signals are to be received with low static level. Intelligent use of the volume control will not only result in maximum selectivity and freedom from interference, but will also keep the *B* battery drain to a minimum.

For very strong signals, the antenna coupling may also be reduced if desired, although best selectivity is obtained when antenna-coupling and trimmer condensers are adjusted to maximum response as this provides accurate lineup of all three tuned circuits. When using range 1 or 2 for A1 reception, adjust for a low beat note. This will provide maximum selectivity.

Approximate dial settings for the various ranges of the AR-8503 are as follows:

Range 1		Range 2		Range 3		Range 4	
Kilocycles	Tuning	Kilocycles	Tuning	Kilocycles	Tuning	Kilocycles	Tuning
15	5	35	10	100	30	250	27
20	45	40	30	120	50	275	37
25	63	50	55	140	63	300	46
30	73	60	65	160	70	325	53
35	81	70	73	180	77	350	60
40	88	80	80	200	81	375	65
		90	85	220	85	400	69
		100	90	240	89	425	72
				250	91	450	75
						475	77
						500	80
						525	82
						550	84
						575	85
						600	86

On early models, the crystal detector is mounted on the rear of the removable tube door. For emergency operation when no spare tubes are available or if the receiver power supply is disabled, proceed as follows. Remove tube door with crystal detector, and place it near antenna and ground posts of receiver. Remove plug from phone cords. Connect crystal and phones in series. Connect the other side of crystal to the post directly below the ground post. Connect the other side of phones to ground post. These connections for crystal operation are clearly shown in the diagram. Later models of the AR-8503 receiver do not use a crystal detector mounted at the rear of the tube door. Instead a sepa-

which are silver plated. The main condenser shaft near the front panel and the shaft extensions for the selector switches near the panel may also be given one drop of oil at each semiannual inspection. When withdrawing the chassis from the cabinet, it should be pulled straight out, taking care not to damage the selector switches, which clear the cabinet by a small amount.

When inserting tubes for the first time, refer to the tube layout on the diagram, which shows the relative position of the tubes. The two tubes nearest the tube door in the front row are 6K7 and also the tube to the left in the rear row. The tube to the right in the rear row is the 6F6.

e. Tube Characteristics.—The 6K7 is a triple-grid supercontrol amplifier. The heater rating is 6.3 volts and 0.3 amp. At 90 volts plate and screen potential, the tube has an amplification factor of 400, a plate resistance of 0.315 megohms, and mutual conductance of 1,275 (with 3-volt grid bias). The 6F6 pentode, which is used as the second audio amplifier, has a 6.3-volt 0.7-amp. heater rating, a plate resistance of 80,000 ohms, an amplification factor of 200, and a mutual conductance of 2,500. All tubes use the same *Universal* eight-prong socket, with a keyway in the center section, so that it is important to place the correct tubes in their respective sockets.

For special applications of the AR-8503 receiver for operation from a power supply of 110 volts, 60 cycles, a separate rectifier unit is furnished. This rectifier unit is called the type RM-6. The necessary internal and external connections are shown in Fig. 14-4. A type 5W4 tube is used in the rectifier. The drain from the 110-volt 60-cycle line is approximately 35 watts.

2. MACKAY MODEL 117-B. *a. Description.*—The receiver is designed for shipboard use. It is of the tuned radio-frequency type with regenerative detector. It is suitable for reception of both A1 and A2 signals. The total frequency range of this receiver is 16 kilocycles to 18 megacycles, divided into several ranges, each range being covered by a coil unit which is inserted into the receiver from the front. The design allows flexibility on the choice of antenna equipment, separate connections being provided for high- and low-frequency antennas. It is also adapted to various types of direct-current power supply. A photograph of this receiver is shown in Fig. 14-5.

The various coil units normally available have a frequency range as follows:

Coil A (VLF).....	16	– 35	kilocycles
B (LF).....	100	–200	kilocycles
C (MF).....	300	–550	kilocycles
D (HF).....	5.2	– 9.0	megacycles
E (HF).....	7.5	–12.7	megacycles
F (HF).....	11.5	–19.5	megacycles

b. Electrical Design.—A simplified schematic diagram of this receiver is shown in Fig. 14-6. It is seen that the receiver consists of one stage of tuned radio-frequency amplification, a regenerative detector, and two stages of audio-frequency amplification.

The tuning of the receiver is accomplished by means of a gang condenser having two sections of 210 mmf. each and two of 450 mmf. each. For the high-frequency ranges, only the 210-mmf. sections are used, one

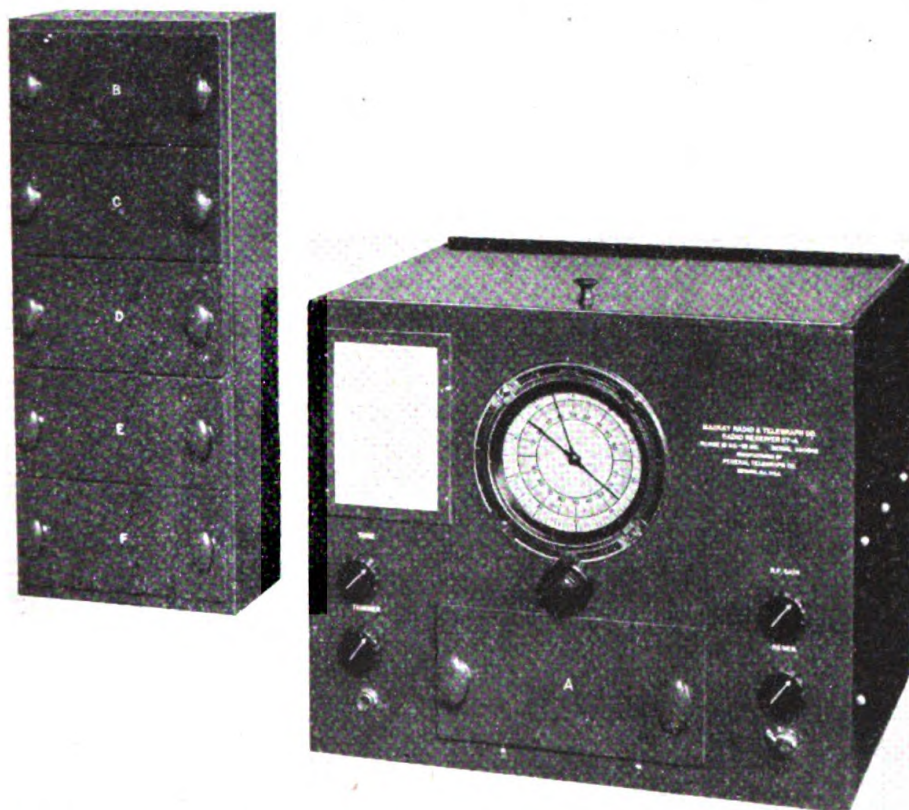


FIG. 14-5.—Mackay Model 117-B marine radio receiver. (Courtesy of Mackay Radio and Telegraph Co.)

being in the radio-frequency tuned circuit and the other in the detector tuned circuit. When a coil unit of a medium-, low-, or very low frequency range is plugged in, connections within the coil unit parallel one of the 450-mmf. sections with each of the 210-mmf. sections. In addition, there is a 100-mmf. variable trimmer condenser across the radio-frequency tuned circuit at all times.

The radio-frequency-amplifier tube is a radio-frequency pentode of the remote cutoff type. Its gain is controlled by a potentiometer, marked R. F. GAIN, which controls the grid bias of the tube. Regeneration is provided by a similar radio-frequency pentode, the degree of regeneration being adjusted by a potentiometer which controls the screen-grid voltage of this tube. Detection is by a triode operating as a grid-bias detector. The first audio stage is also a triode, whereas the second stage is an audio-

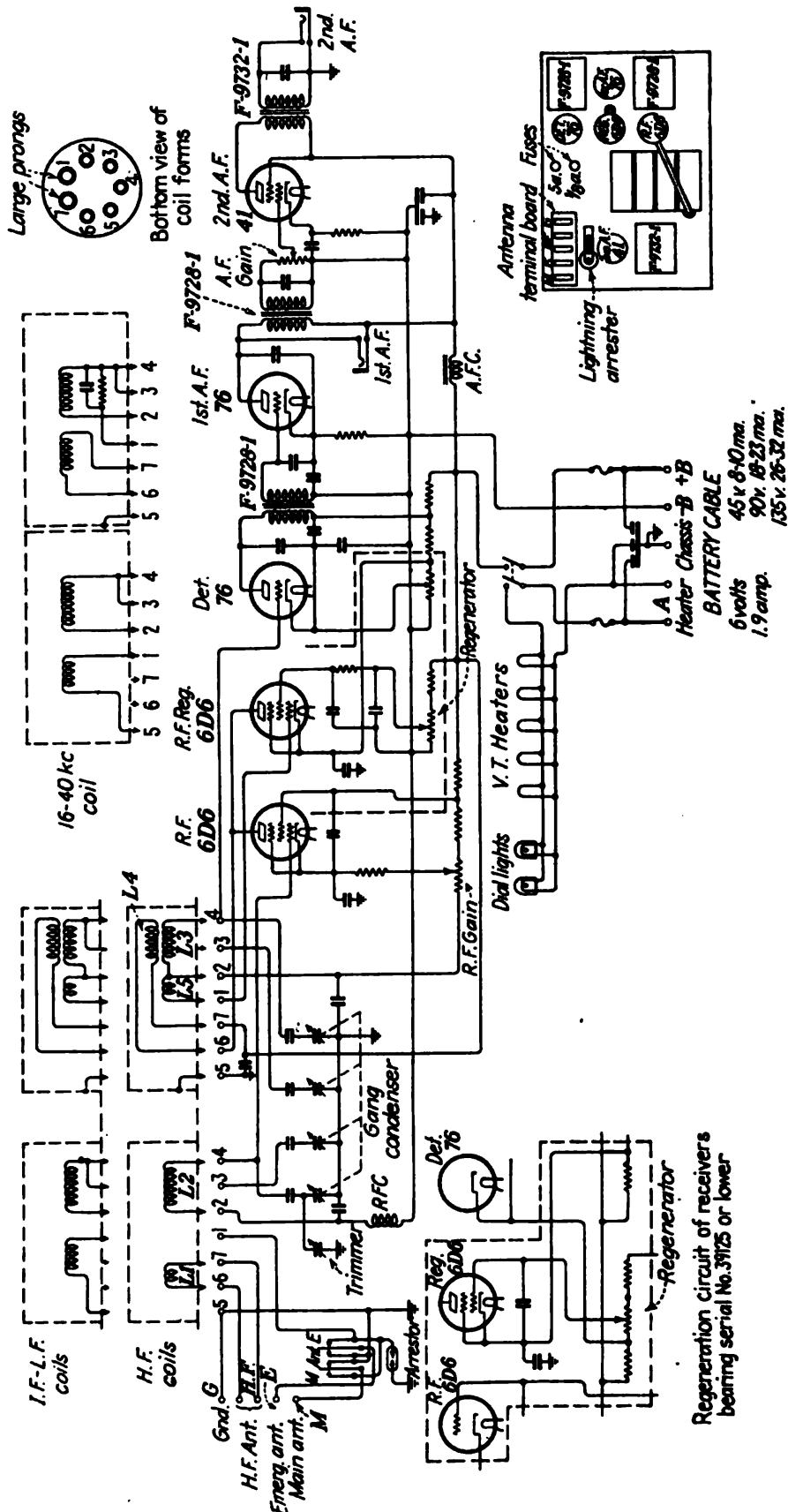


FIG. 14-6.—Mackay Model 117-B radio receiver circuit.

frequency pentode. In receivers carrying serial numbers smaller than 38191, a "tone control" is provided across the grid circuit of the second audio tube. In receivers with higher serial numbers, this tone control is replaced by an audio-frequency gain control, a potentiometer across the secondary of the second audio transformer. The audio-output transformer matches the 20,000-ohm plate resistance of this tube to a load such as a pair of 2,200-ohm phones. The power output is 300 mw. sufficient for a loud-speaker. The latter should match 20,000 ohms either in its own windings or through a suitable transformer.

c. Theoretical Operation.—The progress of the signal through the receiver may easily be traced. For example, when a high-frequency coil is plugged in, the signal from the antenna is impressed on the primary coil L_1 , which is inductively coupled to L_2 of the radio-frequency tuned circuit, L_2 , and the front 220-mmf. section of the gang condenser and the trimmer. The signal on L_2 drives the radio-frequency amplifier grid, whose plate drives L_4 , the primary of the detector coil. The detector tuned circuit consists of L_3 and the rear 210-mmf. section of the gang condenser. Coil L_3 is connected to the detector grid, whereas the regenerator grid is driven by a coil L_5 , coupled to L_3 . The regenerator plate is in parallel with the radio-frequency plate and drives L_4 .

The progress of a medium-, low-, or very low-frequency signal is essentially the same as that of the high-frequency signal just described, except that larger tuning condensers and a grounded antenna may be used.

d. Antenna Requirements.—The antenna posts for the high-frequency ranges are independent of those for the medium-, low-, or very low frequency ranges. To the high-frequency posts may be connected a small antenna and ground, or a transmission line from any suitable high-frequency doublet. For the medium-, low-, and very low frequency ranges, posts are provided for a main antenna and for an emergency antenna, with a switch to connect the input coil to either antenna. There is a lightning arrester to drain excessive static from these latter antennas.

The various types of antenna and tuning-condenser connections are made clear on the schematic diagram by showing the three types of coil windings used for the various frequency ranges. The contacts of the sockets into which the coils are plugged are indicated by two rows of terminals, each numbered 5, 6, 7, 1, 2, 3, 4. Arrows above these circles represent the prongs on the coil forms.

Five terminals on a strip at the rear of the top surface of the chassis are marked M, E, H.F., GND, for connecting the various antennas and the ground. The post marked GND is connected directly to the chassis within the receiver. When a doublet or other antenna with a transmission line is used for high-frequency reception, the two sides of the line should be connected to the two posts marked H.F. If, instead of a doublet, a small single wire is to be used, it should be attached to one of

these posts and the other post should be connected to the ground. If a large Marconi antenna is used for high-frequency reception, a small fixed mica condenser of about 0.00005 to 0.0005 mf. must be connected in series with the antenna. The procedure on a ship with only one antenna will be discussed below.

For the medium-, low-, and very low frequency ranges, the large main antenna is to be connected to the post marked M. The post marked E may be used in several ways. On ships where there is an emergency antenna installed, it should be connected to the E post. On other ships with only a main and a high-frequency antenna, the E post and one H.F. post may be connected together to this antenna.

When the ship has only one antenna this should go direct to the M post. A small fixed condenser is then connected between M and E; E is jumped to one of the H.F. posts and the other H.F. post is grounded. Where this antenna is very large, resulting in broadcast interference on the intermediate frequencies in or near harbor, the fixed condenser should be very small, about 0.00005 mf. When such a small condenser is used where only one antenna is used, it is necessary to remove the ground connection from the M ANT. E switch.

e. Power Supply.—The heater and plate-supply cable from the chassis is provided with a terminal cord which fits in an engraved terminal block which is supplied for convenience in connecting the batteries. The schematic diagram shows the current drains from the A and B batteries. The heaters are connected in parallel for operation from a storage battery or from alternating current.

The B supply may be obtained from 45, 67, or 90 volts of B batteries or from direct-current mains in conjunction with a suitable filter or eliminator. The wire in the battery cable which connects to the "chassis" terminal on the terminal block is for a by-pass condenser to $-B$ in case the latter is not grounded, such as when the B supply is obtained from direct-current mains. The heater and plate-supply circuits within the receiver are independent of each other and of the chassis, thus permitting flexibility in choice of source of supply.

The tubes and fuses required in the receiver are indicated by a stamping at each socket on the chassis. A sketch on the schematic diagram also indicates their positions. These and other parts requiring occasional replacement are shown in the table on page 737. RCA tubes are recommended by the manufacturer of this receiver.

f. Service Notes.—It is desirable to lubricate the prongs of the coil forms occasionally in order to overcome friction which would develop otherwise. It is recommended that a small quantity of light grease be worked into a rag, which is then used to wipe the prongs in such a manner as to apply only a very thin coat of grease over the whole surface of each prong.

If the receiver becomes noisy during operation of the tuning knobs, remove rotor contact springs from the gang condenser and wipe off with a cloth. It is recommended that a very small amount of No. 20 FW Gredag be then applied to the contacting surfaces. In replacing springs, there should be one spring inserted on each side of the rear gang and one on either side of shield between middle gangs. The one to which the spaghetti-covered lead is soldered should be inserted at the rear of the front gang.

Quantity	Type	Description
2	6D6	(a) R.-F. amplifier (b) Regenerator
2	76	(a) Detector (b) First A.-F. amplifier
1	41	Second A.-F. amplifier
2	40	Mazda pilot lights (6.3 volts)
1	1080	Littelfuse 5 amp. type 3AG fuse
1		Littelfuse $\frac{1}{8}$ amp. special 3AG fuse
1	B-Special	L.S. brack arrester with 75-volt tube

g. Operation.—The operation of the receiver is very simple. The functions of the main tuning control and the four auxiliary knobs have been described previously. These four controls have the conventional designations, R.F.GAIN, REGEN, TONE, TRIMMER. In receivers with serial numbers after 38191, the tone control has been replaced, as stated before, by a control on the audio-frequency amplifier and is now labeled A.F.GAIN. There are two phone jacks and two switches. One jack is in the first audio-frequency stage, and the other is the second audio-frequency or output stage. One switch is marked M ANT. E, for transferring between the main and emergency antennas. The other switch controls the A and B battery supplies. A card holder is provided for a card on which to log stations.

The regeneration control should be operated near the point of oscillation at all times: just above it for A1 signals; and either just below or just above it for A2 signals.

The tone control may be used for discriminating against high-frequency background noise. For the 16- to 40-kilocycle range, the tone control should be placed at its left position to suppress singing of the receiver, as the frequencies of this range border on the audio and they, therefore, pass through the audio-frequency amplifier to some extent.

In logging stations, the positions of both pointers of the dial are to be noted. The slow black pointer should be read on the inner scale numbered 0 to 18 in 180 degrees, and the fast red pointer should be read on the outer scale numbered 0 to 100 in 360 degrees.

14.9. Emergency Receivers.—The term *emergency receiver* means a receiver immediately available in a ship station for emergency communication and capable of being energized solely by the emergency power supply.

MACKAY MODEL 122-A and B. *a. General Description.*—This receiver is intended as a stand-by ship receiver for listening on the medium-frequency marine band of 300 to 550 kilocycles, particularly during silent periods. When used in conjunction with radio receiver 117 or any other marine receiver, it allows a quick shift to the 600-meter band without disturbing the setting in use at the time on that receiver. The shift between the receivers is accomplished by means of a switch which simultaneously throws the antenna and phones either to the regular receiver or to stand-by receiver. The electrical design is quite simple, but the sensitivity and selectivity are good for a simple receiver. Various types of direct-current power supply may be used.

b. Mechanical Design.—The receiver has been made of a height, depth, and general mechanical design uniform with radio receiver 117. The cabinet is easily removed from the base, and the chassis is easily removed from the cabinet. A lid on the top of the cabinet provides access for changing tubes and making antenna connections.

c. Electrical Design.—The schematic diagram of the receiver is shown in Fig. 14-7. There is a detector with separate regenerator tube, and one stage of audio-frequency amplification. All tubes are pentodes. There are two tuned circuits loosely coupled together. The antenna coil is coupled to the antenna by a 0.0001-mf. condenser. The detector-coil system, indicated on the schematic diagram as F-7594-1, consists of three coils. The center tuned coil is of high Q and drives the detector grid. The two side windings are for the grid and plate of the regenerator tube. The degree of regeneration is controlled by a potentiometer supplying the screen-grid voltage. The detector tube is impedance coupled to the audio tube, which is in turn impedance coupled to the output.

The switch for transferring the antenna and phones from the regular receiver to the type 122 receiver is shown at the top of the schematic diagram. A leak resistance is provided to drain static charges on the antenna to ground, preventing the accumulation of high static potentials on the coupling condenser.

Heater-supply connections are such that they may be operated from a 6- or 12-volt storage battery, or in series from direct-current mains. Both heater- and plate-supply connections within the receiver are independent of the chassis and of each other, in order to allow latitude in choice of sources of supply.

d. Operation.—On the front panel is the detector-circuit tuning knob and scale toward the top and the antenna-circuit tuning knob near the bottom center. These knobs are mounted directly on the respective

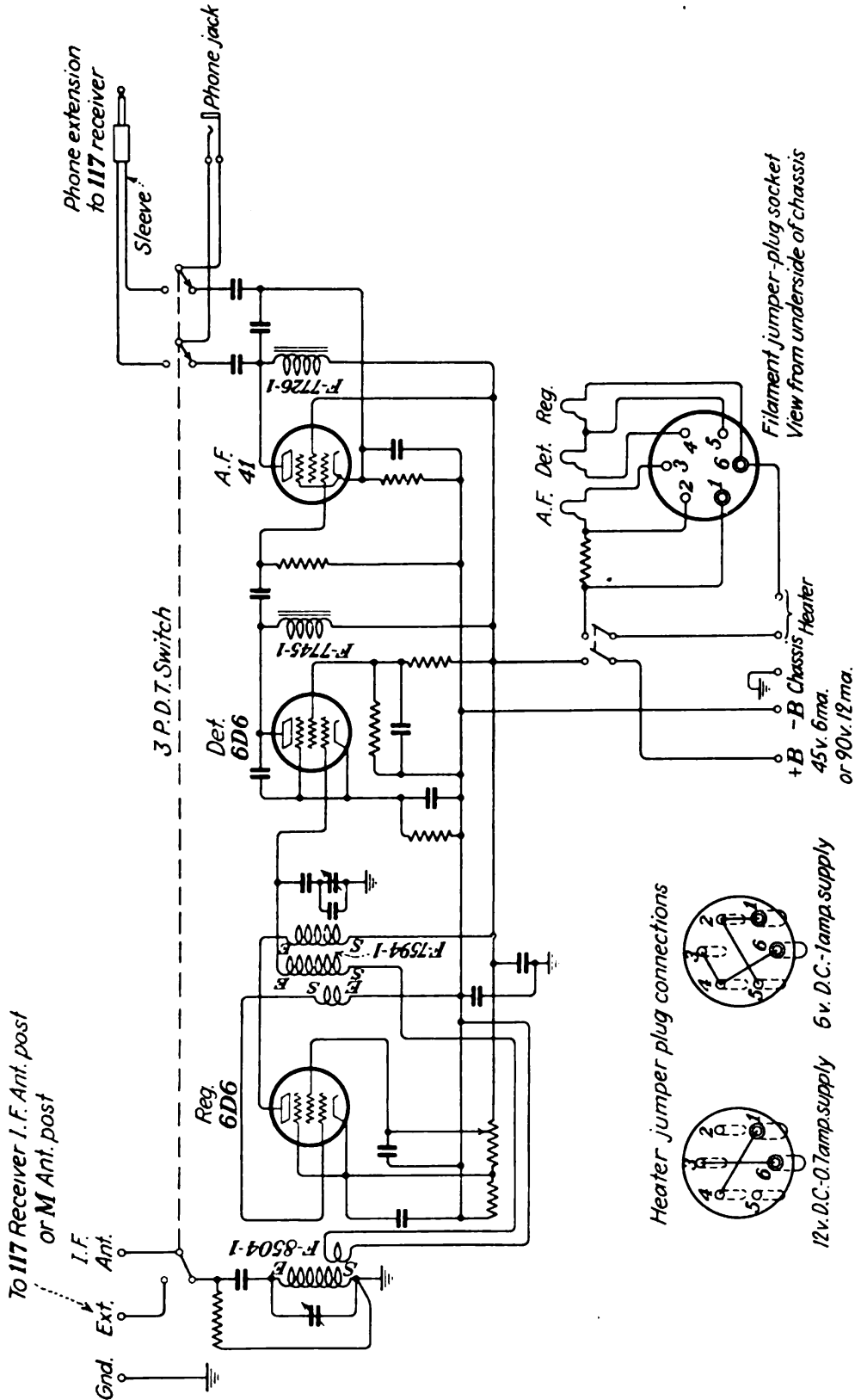


FIG. 14-7.—Mackay Model 122B radio-receiver circuit.

condenser shafts. Below the detector tuning knob is the regeneration control knob. This should be operated near the point where oscillation commences, for maximum gain and selectivity. Next are the battery switch and the transfer switch for switching from the regular receiver to the type 122 receiver. At the bottom are a phone jack and an extension cord and plug for plugging into the phone jack of the regular receiver. The phones may remain plugged into the jack on the stand-by receiver at all times.

e. Installation.—The medium-frequency antenna is to be connected to the post on the chassis of the 122 receiver marked I.F. ANT. Connect a jumper from the post marked EXT. to the medium-frequency antenna post of the 117 or other receiver used for regular traffic. A ground is run to the post so marked, which is connected to the chassis within the receiver.

The heater and plate supplies are in a five-wire cable provided with a terminal cord which fits into an engraved terminal block to be mounted at a convenient place for connecting batteries. The schematic diagram shows the cross connections of the filament jumper plug for operation from 6 volts, 12 volts, or in series, with an external dropping resistor. This plug is to be inserted in the rear socket on the chassis.

A 45-volt *B* supply is recommended, but 90 volts may be used. The *B* supply may be obtained from batteries or from power mains in conjunction with a suitable eliminator. If the receiver is supplied by an eliminator from direct-current mains, the same eliminator may be used for both the 117 receiver and the 122. The heaters of the two receivers may be operated in series, and the *B* and chassis terminals in parallel. The terminal marked CHASSIS is for a by-pass to $-B$ when the latter is not grounded and requires filtering.

The position of the tubes required in this receiver are stamped on the chassis. The tube types are shown below:

Quantity	RCA Type	Function
2	6D6	(a) Regenerator (b) Detector
1	41	A.-F. amplifier

14.10. High-frequency Receiver. R.M.C.A. MODEL AR-8505. *a. General Description.*—This receiver is a seven-tube superheterodyne designed primarily for marine services for high-frequency reception. The receiver covers a continuous frequency range from 540 to 30,000 kilocycles. No plug-in coils are required, since any frequency within the range specified may be quickly obtained by means of panel controls. A photograph of this receiver is shown in Fig. 14-8.

The AR-8505 receiver has the following features:

1. Full-vision tuning dial calibrated directly in kilocycles.
2. Electrical band spread with separate tuning condensers.
3. Continuous-frequency coverage with four-position band switch.
4. Individual coil systems for each tuning range.
5. Separate audio- and radio-frequency gain controls.
6. Panel switches for *AVC* and *C-W* oscillator control.
7. Operation from either alternating-current or direct-current power supply.
8. Provision for doublet receiving antenna.

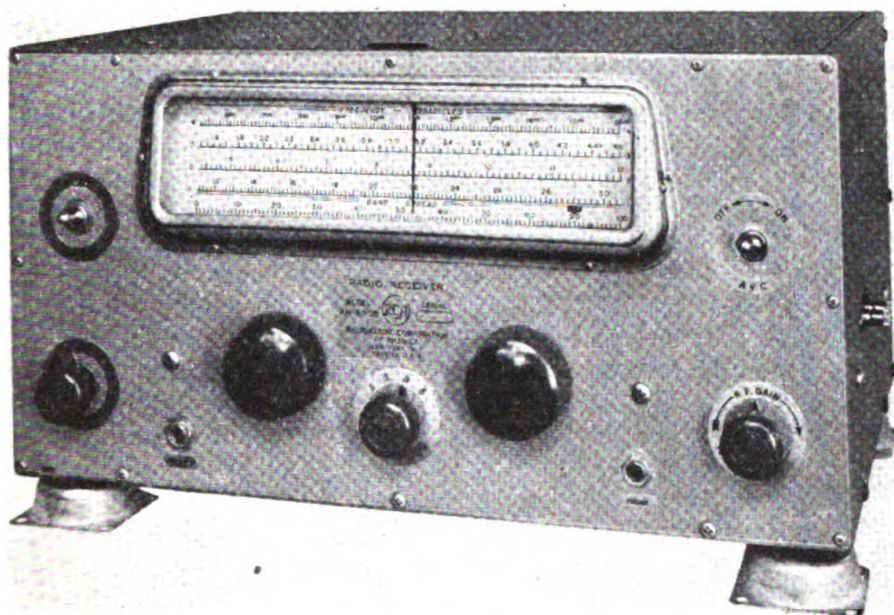


FIG. 14-8.—R.M.C.A. Model AR-8505 marine radio receiver. (Courtesy of R.M.C.A.)

The following RCA tube complement is used in the AR-8505 receiver:

- 6K8 mixer oscillator.
- 6L7 first intermediate amplifier.
- 6L7 second intermediate amplifier.
- 6SQ7 second detector, first audio, and *AVC*.
- 25L6G second audio amplifier.
- 6J7 *C-W* oscillator.
- 25Z5 rectifier.

Access to all tubes is obtained through a hinged cover on the cabinet.

The tuning ranges of the receiver, in kilocycles, are as follows:

Range 1, high frequency.....	11,200 to 30,000
Range 2, high frequency.....	4,400 to 12,000
Range 3, medium and high frequencies.....	1,500 to 4,600
Range 4, medium frequency.....	540 to 1,600

The full-vision tuning scale is calibrated in kilocycles and, in addition, provided with a 0 to 100 scale for calibration or logging purposes.

The medium frequency of the receiver is 456 kilocycles. Three medium-frequency transformers are used and are of the tuned iron-core type.

The receiver is designed to operate directly from a 110-volt direct-current or alternating-current power supply, and requires a line current of approximately 0.37 amp. or 40.7 watts. For operation from a 230-volt direct-current or alternating-current line, an external resistor of 325 ohms (75 watts) is required, and this resistor is required as an additional item for applications where the supply is 230 volts.

For headphone reception, high-resistance telephone receivers having a direct-current resistance of 2,000 or 3,000 ohms should be used. For loud-speaker reception, a standard 4-ohm voice coil type of permanent-magnet loud-speaker is recommended. The output transformer from the second audio amplifier in the receiver is mounted in the chassis so that an additional matching loud-speaker transformer is not required.

The AR-8505 receiver has the following panel controls:

1. Main tuning scale.
2. *C-W* on-off switch.
3. *AVC* on-off switch.
4. Audio-frequency gain control.
5. Radio-frequency gain control.
6. Main tuning control.
7. Band-spread tuning control.
8. Band switch.
9. Headphone jack.
10. Loud-speaker jack.

Binding posts for connection to a doublet antenna are mounted on the right side of the cabinet. A fuse block for the incoming power line is located in the left corner of the chassis. Two Littelfuse fuses No. 5 AG, 1-amp. rating, catalogue No. 1160, code GOB, are used.

The AR-8505 receiver is furnished with a spare tube for each socket, and 4 spare fuses (Littelfuse No. 5 AG, 1 amp.).

The sensitivity of the AR-8505 receiver is such that for *C-W* reception a readable headphone signal may be obtained with an input at the antenna terminals of 1 to 2 μv . For reception of modulated waves, not using the *C-W* oscillator, an input of 2 to 10 μv is required, depending on the frequency band in use.

The selectivity of the AR-8505 receiver is shown on the selectivity curve Fig. 14-9. Particular attention is directed to the high degree of selectivity that is available for adjacent channel interference so that interfering signals which are removed from the desired signal by 5, 10, or 15 kilocycles are highly attenuated. For example, in the marine high-frequency band if the receiver is tuned to 5,545 kilocycles, an interfering signal in the next channel such as 5,550 kilocycles is attenuated approxi-

mately thirty times. Likewise, if the receiver is tuned to 8,450 kilocycles, an interfering signal in the adjacent channel of 8,440 kilocycles is attenuated by a factor of approximately 500.

b. Installation.—When the receiver is installed, it is recommended that the doublet antenna leadin which connects to the binding posts on the right side of the cabinet should be run in shielded twin-conductor wiring for locations where considerable external noise is prevalent. A

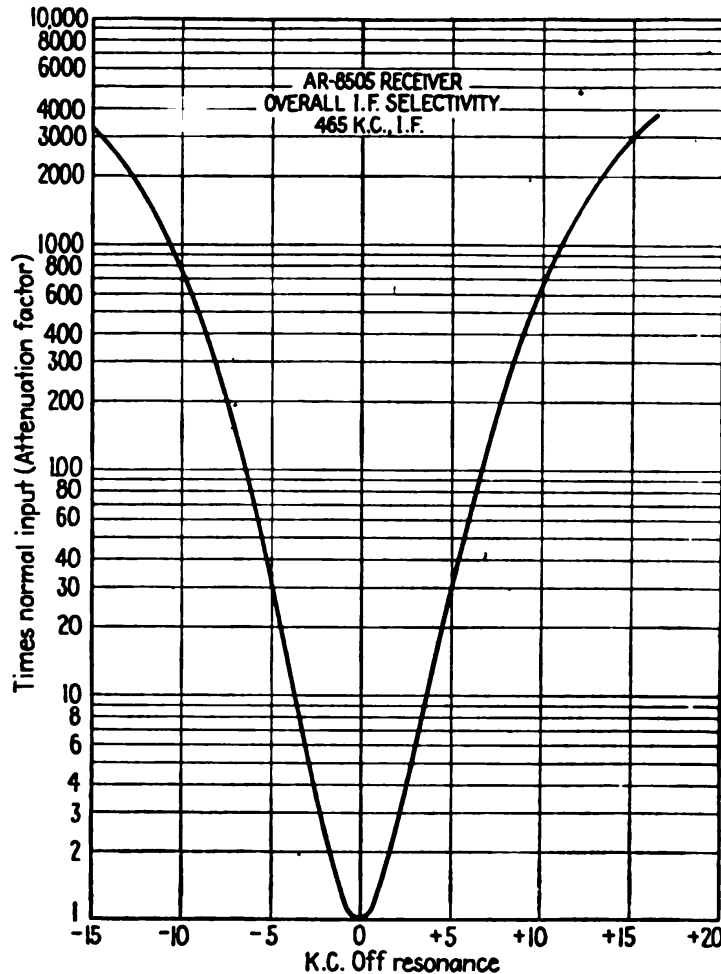


FIG. 14-9.—R.M.C.A. type AR-8505 receiver over-all I.F. selectivity.

standard marine type doublet antenna is recommended, this antenna to have an over-all length of approximately 60 ft., broken in the center with an insulator, and a suitable low-loss twisted pair leadin used to connect the center of the doublet to the AR-8505 receiver.

The internal chassis of the receiver is insulated from the cabinet, and care should therefore be taken not to make any ground connections to the chassis. A ground connection may, however, be made to the external cabinet if it is found that in some installations such a connection will reduce local noise pickup.

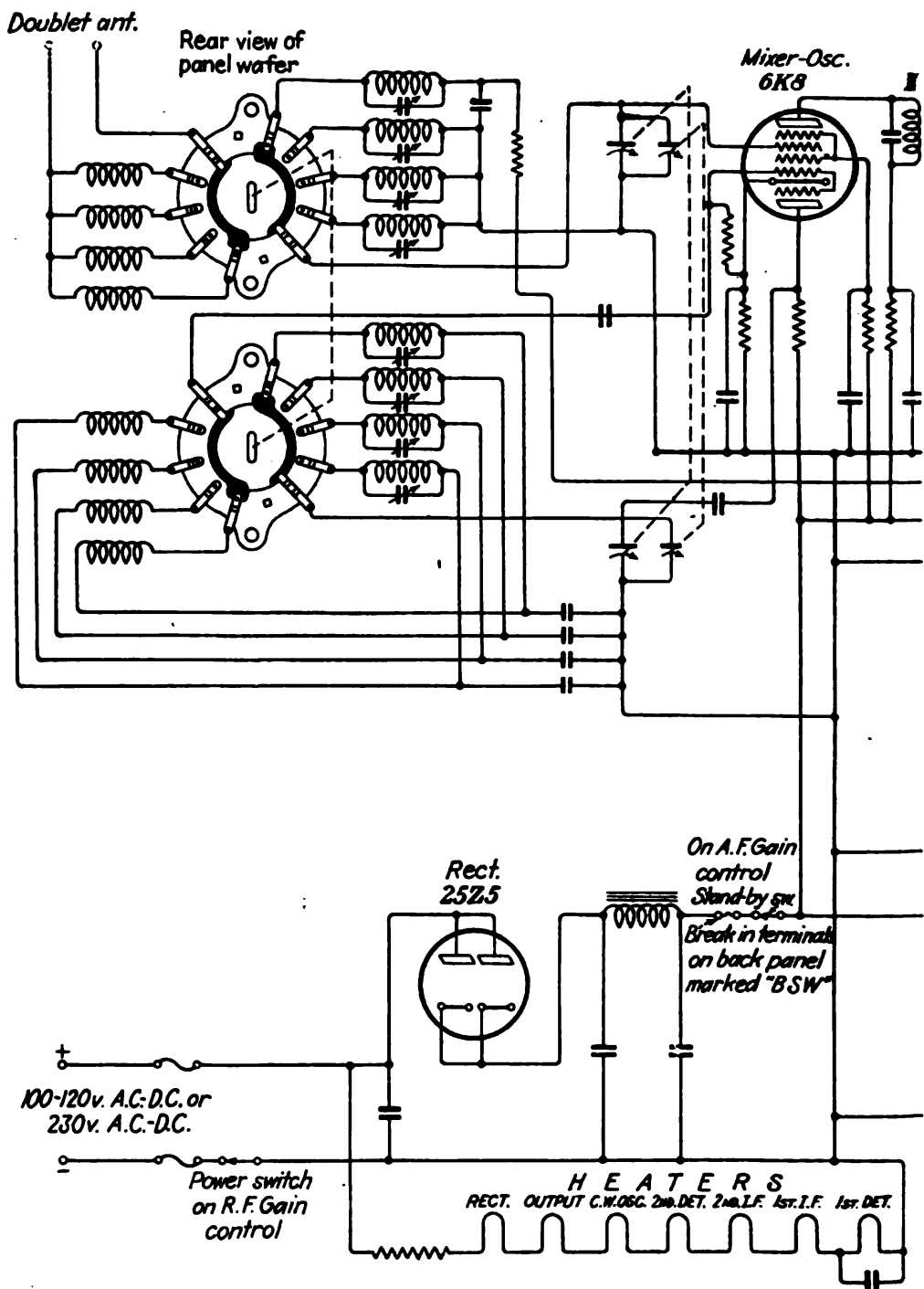
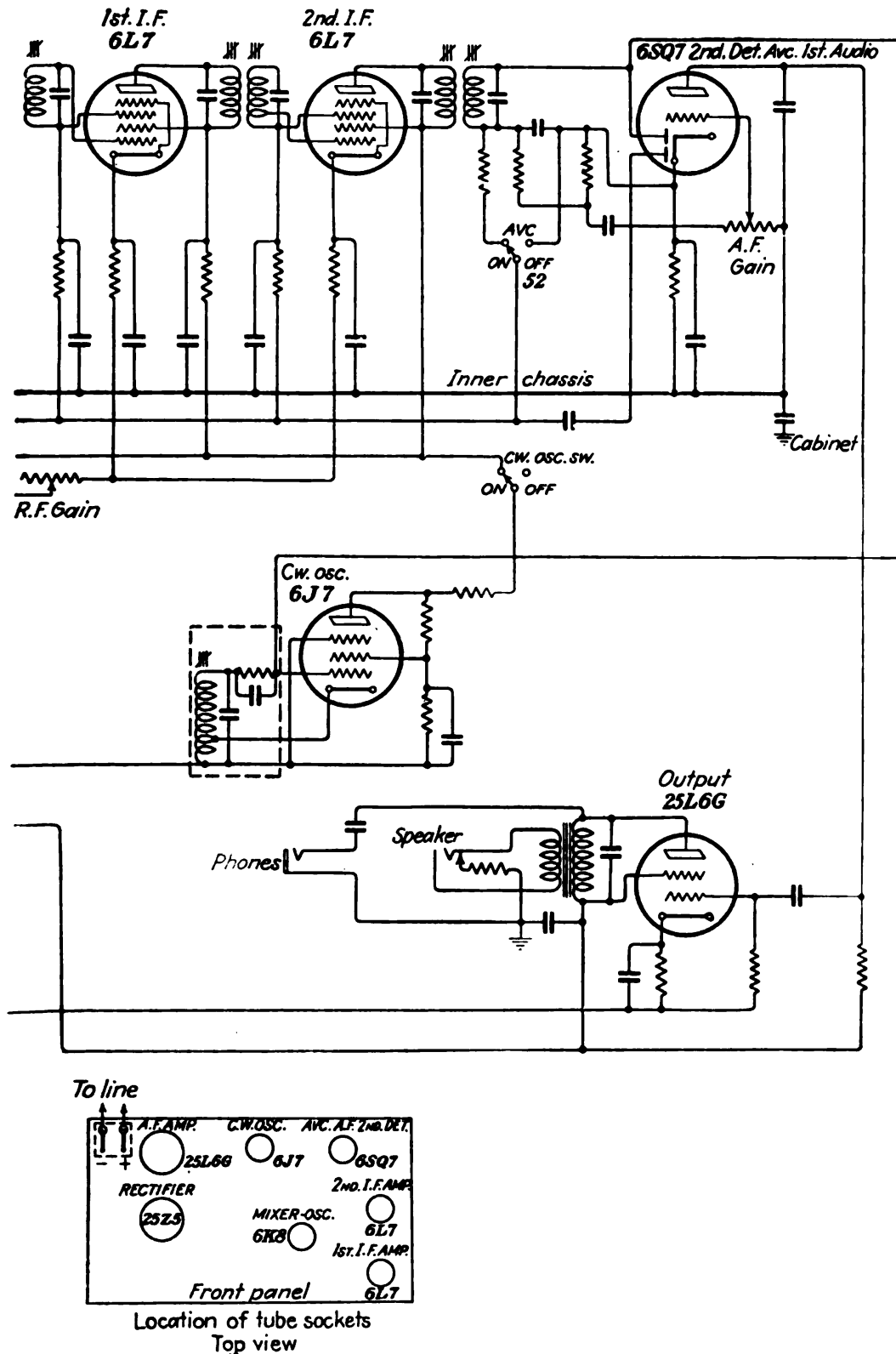


FIG. 14-10.—RMCA Type



AR-8505 receiver circuit.

The small terminal board at the rear of the cabinet marked BSW is provided with a jumper connection which should be kept tight at all times. This terminal block is provided for special installations where it is found necessary to break the *B* supply to the receiver by means of an external switch or relay. The *B* supply circuit is also opened when the audio-frequency gain control is turned to the full counterclockwise position.

A complete connection diagram of the receiver is shown in Fig. 14-10. The leadin from the doublet antenna passes through one section of the band switch to select the desired primary winding for the frequency band that is to be used. Other sections of the band switch select the appropriate grid coil for the mixer circuits of the 6K8 tube and also the appropriate plate and grid coils for the oscillator section of the 6K8 tube. The plate circuit of the 6K8 connects to the primary of the first medium-frequency transformer, while the secondary of this transformer is connected to the grid circuit of the first 6L7 medium-frequency amplifier in the conventional manner.

The second medium-frequency amplifier is connected as shown and feeds into the various circuits of the 6SQ7 tube. The 6SQ7 functions as a second detector, *AVC*, and also as the first stage of audio amplification. The audio output of this tube is coupled to the control grid of the 25L6G second audio amplifier. The primary winding of the 25L6G output transformer is connected through blocking condensers to the headphone jack, whereas the secondary winding connects to the loud-speaker jack. The loud-speaker jack is arranged so that when the loud-speaker is disconnected a 4-ohm resistor is placed across the secondary winding to maintain a correct load on the output tube.

The 6J7 *C-W* oscillator tube is arranged to operate at a frequency approximately 1 kilocycle above or below the medium frequency of 456 kilocycles. The output of the 6J7 tube is coupled to one of the diodes of the second detector through a 2-mmfd. condenser.

All heaters of the tubes are wired in series and are connected through a 95-ohm resistor to permit operation directly from a 110-volt source. The 25Z5 rectifier tube functions in the conventional manner for alternating-current supply, and in the case of direct-current supply is used to prevent damage to the electrolytic condensers in the filter network in the event that incorrect polarity is accidentally applied to the power input terminals of the receiver.

c. Operation.—The following operating procedure is recommended for best results. The band-spread tuning control should normally be left at 90 on the lower scale below the engraving on the dial mark SET. The main tuning control is calibrated on the basis that the band-spread control is adjusted to 90 or SET.

After a signal is tuned in, the band-spread control may then be used for accurate adjustments. For receiving very weak signals, which do not fade appreciably, the best signal-to-noise ratio will be obtained by leaving the automatic volume control switch off, by adjusting the audio-frequency gain control to a fairly high value, and then by adjusting the radio-frequency gain control to the desired signal level.

In the case of fading signals when *AVC* is required, maximum *AVC* action will be obtained by adjusting the radio-frequency gain control to a high value and then regulating the signal volume by means of the audio-frequency gain control. When receiving under conditions of strong interference from other stations, it will be found helpful not to use *AVC* in order to avoid suppression of the desired signal by the interfering signal, which would otherwise actuate the *AVC* circuits and thus reduce or wipe out the desired signal.

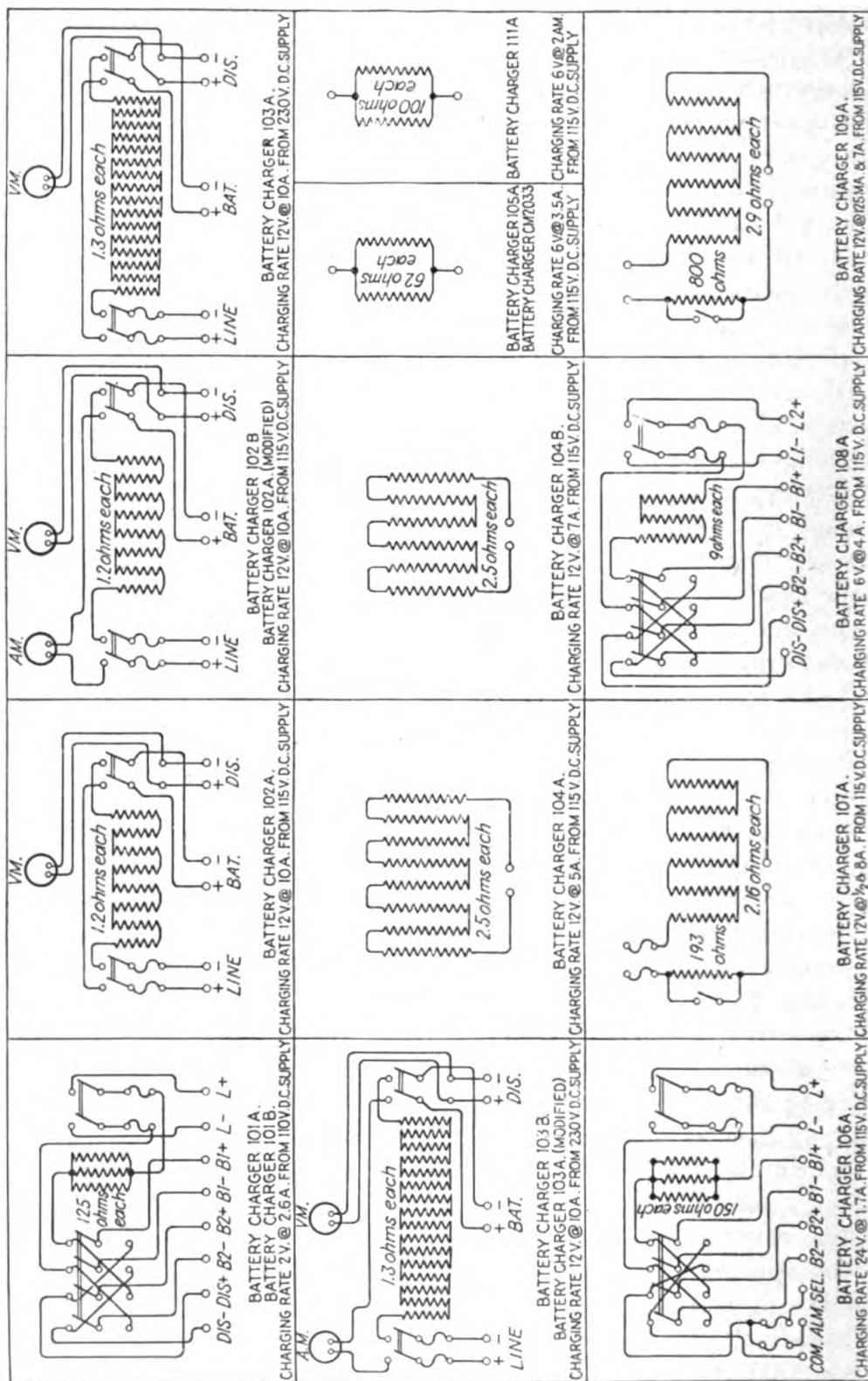
d. Maintenance.—It is not recommended that any attempts should be made to line up the receiver aboard ship by adjusting the medium-frequency transformers or any of the trimmer condensers on the underside of the chassis. Accurate laboratory equipment is required for correct line-up, and any attempts that are made to adjust the various trimmers without suitable test equipment will invariably result in more harm than good and will impair the calibration, sensitivity, and selectivity of the receiver.

If the performance of the receiver becomes subnormal and cannot be restored by replacing tubes, it is recommended that the receiver be returned to the manufacturer for repairs. Filament failure of any tube will result in all tubes running "cold" since the heaters are wired in series. The defective tube should be located by replacing all tubes one at a time, taking care always to replace the *correct type* of tube in its respective socket. The two tubes which use 25-volt heaters are the two glass tubes near the fuse block. All metal tubes are of the 6.3-volt heater type.

Top cover of cabinet should be kept tight with the two hold-down screws at all times to avoid variations in beat note for *C-W* reception. Access to the underside of the chassis is obtained by removing the bottom tray from the cabinet.

Continuity of coils may be checked by means of resistance measurements by referring to the values shown on the diagram. Likewise, all resistors may be checked and condensers tested for shorts with a standard volt ohm-meter. The various socket voltages shown in the following table are measured with a high-resistance voltmeter using a voltmeter scale nearest to the values of the voltage under measurement.

AR-8505 Socket Voltages.—All measurements made with 110-volt direct-current line using a 1,000-ohms-per-volt meter. All voltages are measured to the inner chassis.



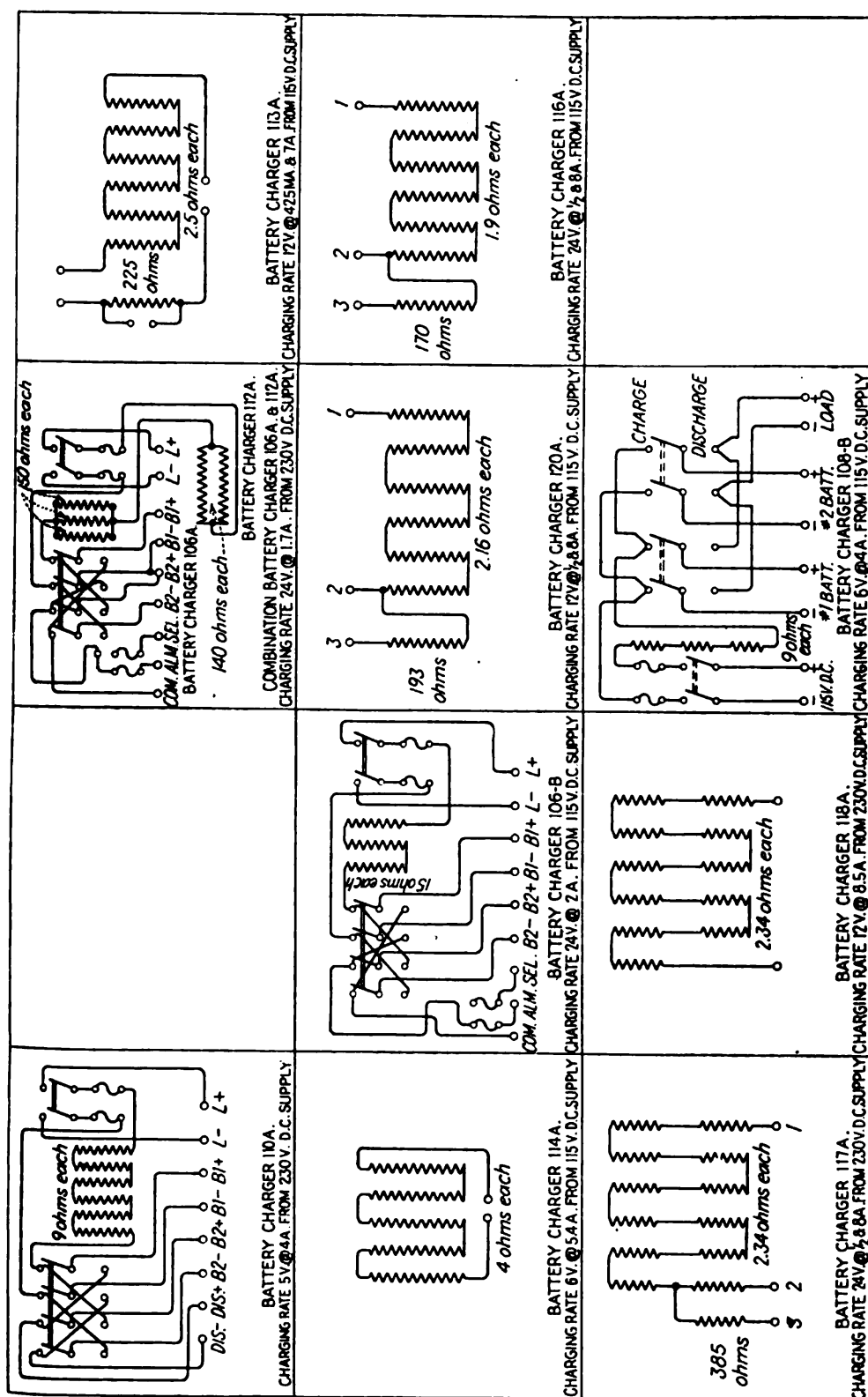


Fig. 14-11.—Circuits of battery chargers for use with Mackay equipment.

AR-8505 SOCKET VOLTAGES

6K8 MIXER-OSCILLATOR

No.	Volts	No.	Volts
1	0.0	5	
2	6.3	6	65.0
3	81.0	7	0.0
4	82.0	8	1.5

6L7 2d I.F.

No.	Volts	No.	Volts
1	0.0	5	0.0
2	12.3	6	0.0
3	84.0	7	18.6
4	84.0	8	2.75

6J7 C-W OSCILLATOR

No.	Volts	No.	Volts
1	0.0	5	0.0
2	25.0	6	83.0
3	28.0*	7	32.0
4	10.0	8	0.0

25Z5 RECTIFIER

No.	Volts	No.	Volts
1	80.0	4	102.0
2	108.0	5	108.0
3	102.0	6	55.0

6L7 1st I.F.

No.	Volts	No.	Volts
1	0.0	5	0.0
2	12.3	6	0.0
3	77.0	7	6.3
4	77.0	8	2.2

6SQ7 2d DET., 1st AUDIO AND AVC

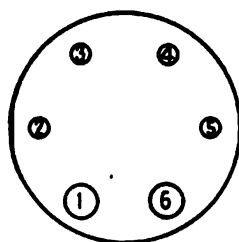
No.	Volts	No.	Volts
1	0.0	5	0.0
2	0.0	6	55.0*
3	0.5	7	25.0
4	0.0	8	18.5

25L6G OUTPUT TUBE

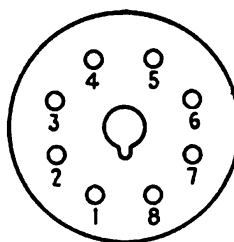
No.	Volts	No.	Volts
1	0.0	5	0.0
2	55.0	6	0.0
3	78.0	7	31.0
4	83.0	8	5.3

* Measured on 300-volt range.

Bottom views of the tube sockets used in this receiver are shown in Fig. 14-12.



(a) 25Z5 Rectifier



(b) Octal tubes

Fig. 14-12.—R.M.C.A. type AR-8505 receiver tube sockets, bottom view.

14.11. Filament Battery Chargers.—Marine radio receivers are generally provided with an independent source of filament power in the form of a storage battery, generally of the lead-cell type. To meet the require-

ments for various filament-battery installations, a number of different charging circuits have been designed. These are shown in the diagrams of Fig. 14-11, which are self-explanatory. The chargers shown are used in Mackay installations and like all Mackay equipment are designed and manufactured by the Federal Telegraph Company.

14.12. Crystal-detector Receivers.—Compulsorily equipped vessels are required to be fitted with a radio receiver independent of any source of power supply. The only practical receiver to answer this requirement is the crystal-detector receiver. The crystal detector rectifies the high-frequency signal waves into unidirectional impulses. These rectified pulsations are impressed across the telephone by-pass condenser. In other words, the rectified signal voltage charges the condenser until its voltage or potential is higher than the applied signal voltage. Then the accumulated charges discharge through the telephone windings, producing one complete vibration. If 1,000 wave trains per second were producing this effect, there would be 1,000 vibrations per second and a musical note would be heard in the headphones.

R.M.C.A. RADIO RECEIVER TYPE B.—This receiver is a crystal receiver designed to meet the requirements of the Safety of Life at Sea Convention and the rules of the FCC. Such regulations require, on vessels subject to the Safety Convention, a radio receiver that is capable of receiving radiotelegraph signals, *A2* or *B* emission, on all frequencies within the band 350 to 515 kilocycles by means of a crystal rectifier, and for this purpose the receiver shall not require the use of electron tubes.

The circuit used in the type *B* receiver and shown in Fig. 14-13 comprises a fixed inductance, a variable tuning capacitor, an adjustable "cat-whisker" type of crystal, a crystal by-pass capacitor and phone jack.

The receiver is adjusted by tuning the variable capacitor to the desired signal and regulating the "cat whisker" to a sensitive spot on the crystal. Since the type *B* receiver is normally used in conjunction with the same antenna as that employed for the ship's main vacuum-tube radio receiver, a single-pole double-throw switch should be installed to transfer the antenna circuit to either the type *B* crystal receiver or the main vacuum-tube receiver.

The type *B* receiver is mounted in a cabinet provided with four mounting brackets and is shown as item 10 in Fig. 14-15.

MACKAY RADIO RECEIVER 123-A-B and 123-B.—This is a simple crystal detector receiver intended for emergency shipboard use in case all other available receivers fail. The receiver is for wall mounting. Its frequency range is 350 to 550 kilocycles, the medium-frequency marine band.

The schematic diagram is shown in Fig. 14-14. On the front panel the tuning knob, whose position may be read on an etched scale, controls the variable condenser in the antenna series tuned circuit. At the lower

left corner is a knob controlling the three-position tap switch for the antenna inductance. The secondary tuning condenser is at the lower right corner of the panel varying from maximum to minimum in 180 degrees. A transmit-receive switch is located at the upper right corner of the receiver and is marked OFF-ON. This switch opens the antenna circuit and shorts the crystal when in the OFF position, to prevent burning of the crystal while transmitting. In this position it also transfers the

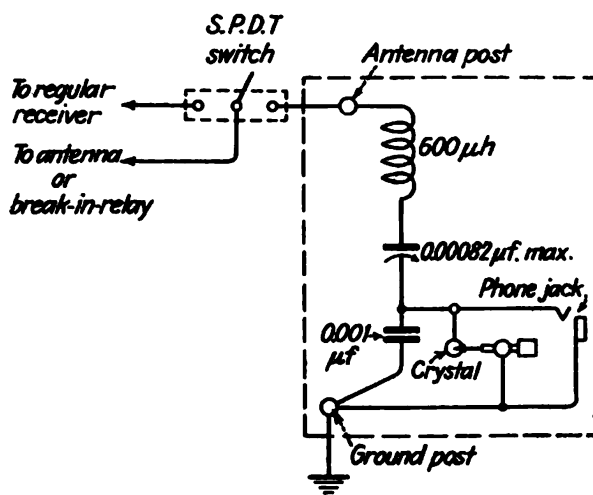


FIG. 14-13.—R.M.C.A. type B radio receiver.

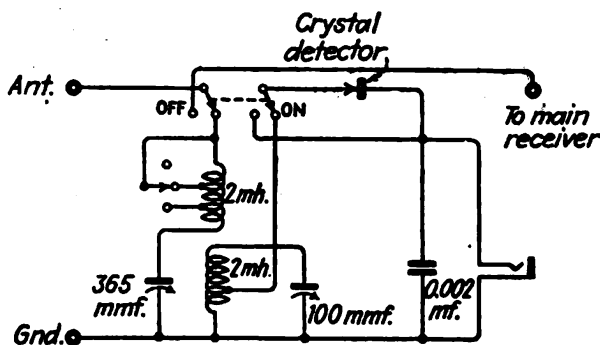


FIG. 14-14.—Mackay model 123 radio receiver.

antenna to a binding post located at the bottom of the cabinet, to which the antenna post of the main receiver may be connected.

The crystal detector on the panel may be adjusted to practically any part of its surface, in searching for a sensitive spot. In tuning in a station, the large tuning knob is the main factor in selecting the signals. However, the proper point of the antenna-coil tap switch should be found by experience to get maximum sensitivity. This switch is provided to take care of various types of antenna installations. The secondary circuit tuning is much flatter than the antenna circuit, but gives considerable improvement in sensitivity and selectivity when tuned to the desired signal. Both tuning knobs turn clockwise for increasing frequency, and the tap switch turns clockwise for decreasing inductance.

14.13. Marine Radio Accessories.—Accessories are usually necessary with every radio installation aboard ship. Some of the most important of these are shown in the photograph in Fig. 14-15. Items 1 and 5 are typical line filter units used with motor generators to reduce radio-frequency interference. Items 2 and 4 are direction-finder signal lights used in the radio room to warn the operator against using the ship's

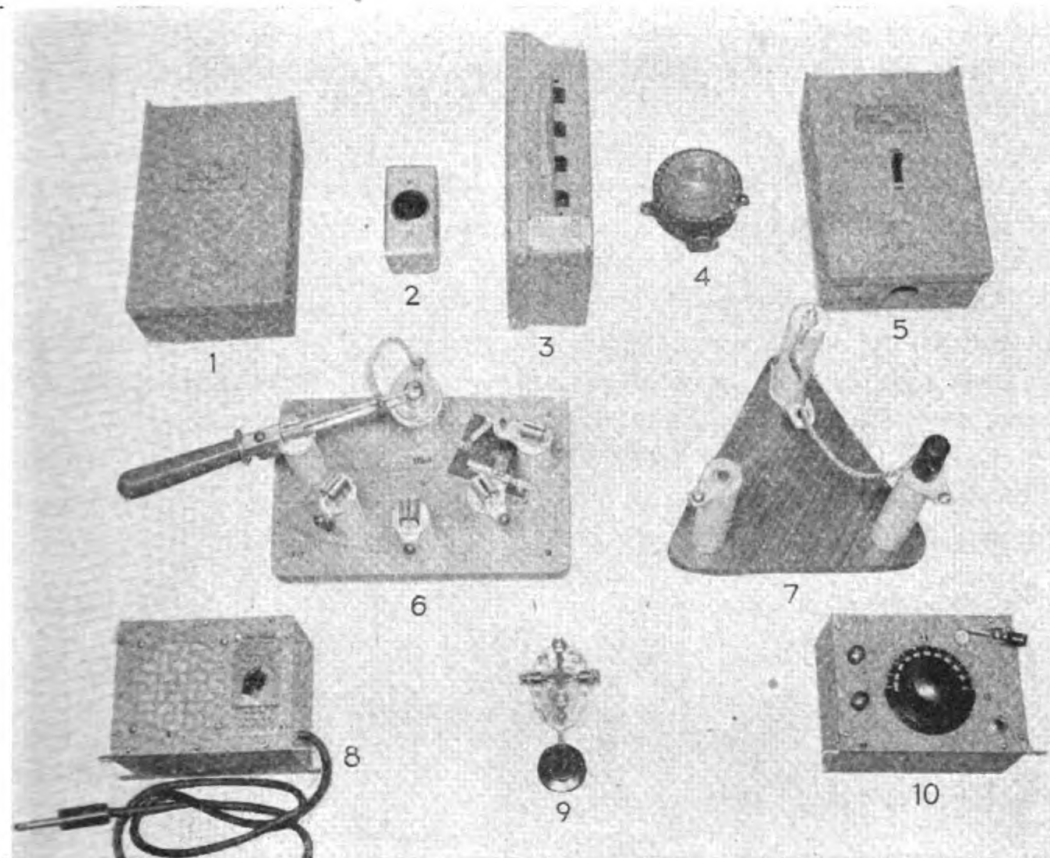


FIG. 14-15.—Marine radio accessories. (Courtesy of R.M.C.A.)

main transmitter when the direction finder, usually located on the navigation bridge, is being used.

Item 3 is a power-transfer switch used where a common motor generator supplies power to an intermediate-frequency or high-frequency transmitter. Items 6 and 7 are typical antenna-transfer switches.

Item 8 is a small loud-speaker with high- and low-impedance input switching. Item 9 is a standard key, and item 10 is the type *B* crystal-detector receiver.

CHAPTER 15

MARINE AUTOMATIC RADIO ALARMS

This chapter deals with two approved automatic-alarm systems, commonly known as *auto alarms*. The function of these devices is to receive automatically the international automatic alarm signal, consisting of a series of 12 dashes sent in a prearranged manner. One of the approved models is equipped also to transmit or key this signal into the main transmitter.

15.1. Approved auto alarms are designed to ring warning bells and light warning lights upon receipt of prearranged signals. These alarm devices are installed on cargo vessels, which are not required by law to have an operator on watch continuously while under way.

1. R.M.C.A. MODEL AR-8600 AUTO ALARM. *a. General Description.* This alarm device, a photograph of which is shown in Fig. 15-1, is designed for bulkhead mounting and consists of the following parts:

Radio receiver and selector unit.

Junction box.

Master switch.

Bridge bell and warning light.

6-volt 75 amp.-hr. storage battery (1 amp. rate).

One box of spare parts consisting of tubes, lights, fuses, fuse links, C battery, filament resistor, and a relay contact burnisher.

A schematic circuit diagram of the complete device is shown in Fig. 15-2.

b. Power-supply Requirements.—The main power supply for the AR-8600 auto alarm is the shipboard 110-volt direct-current line. A current of approximately 1.5 amp. is required. This 110-volt supply is used for all filament circuits, plate circuits, screen circuits, oven heater and warning lights of the auto alarm. A 6-volt storage battery is also used. This battery furnishes energy for ringing the alarm bells and for energizing the stepping relay and auxiliary relay in the auto alarm. The normal current required from the 6-volt battery is 0.4 amp., except when all alarm bells are ringing, when a current of approximately 3 amp. is required.

c. Construction.—Five radio-frequency transformer units are mounted in a row at the upper section of the front panel. Each of these units is constructed with impregnated Litz coils and air dielectric tuning condensers. The coupling between the various radio-frequency coils is adjusted

at the factory to secure the specified band width and selectivity. The first transformer unit in the upper left section of the panel contains the radio-frequency oscillator circuits. The next unit to the right is the 500-kilocycle input transformer. The next three units are the intermediate-frequency transformers.

Directly beneath the radio-frequency units, viewed from left to right, are the following: $\frac{1}{2}$ amp. plate fuse, 6-A-8 mixer-oscillator tube, 6-K-7

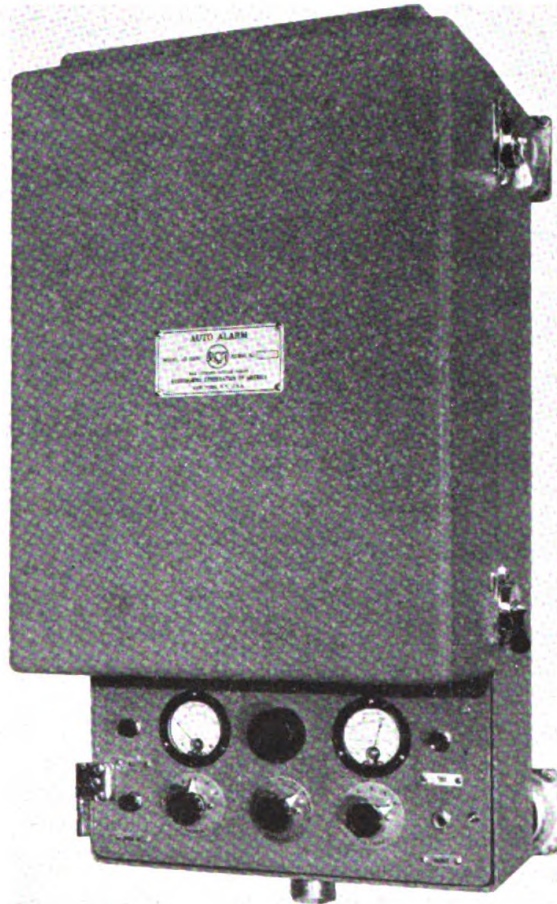


FIG. 15-1.—R.M.C.A. Model AR-8600 auto alarm. (Courtesy of R.M.C.A.)

first intermediate amplifier, 6-K-7 second intermediate amplifier, 6-H-6 diode detector.

The next row of tubes, five type 1611, reading from left to right, are as follows: voltage regulator tube, radio relay tube, first selector tube, second selector tube, third selector tube.

Three selector relays are mounted in a thermostatically controlled oven which is located beneath the tubes. A suitable heater and bimetallic thermostat are used inside this oven to maintain a temperature of approximately 55°C. The electric heater in this oven, which is controlled by the thermostat, is permanently connected to the 110-volt line and operates at all times, whether or not the auto alarm is in use. The heat

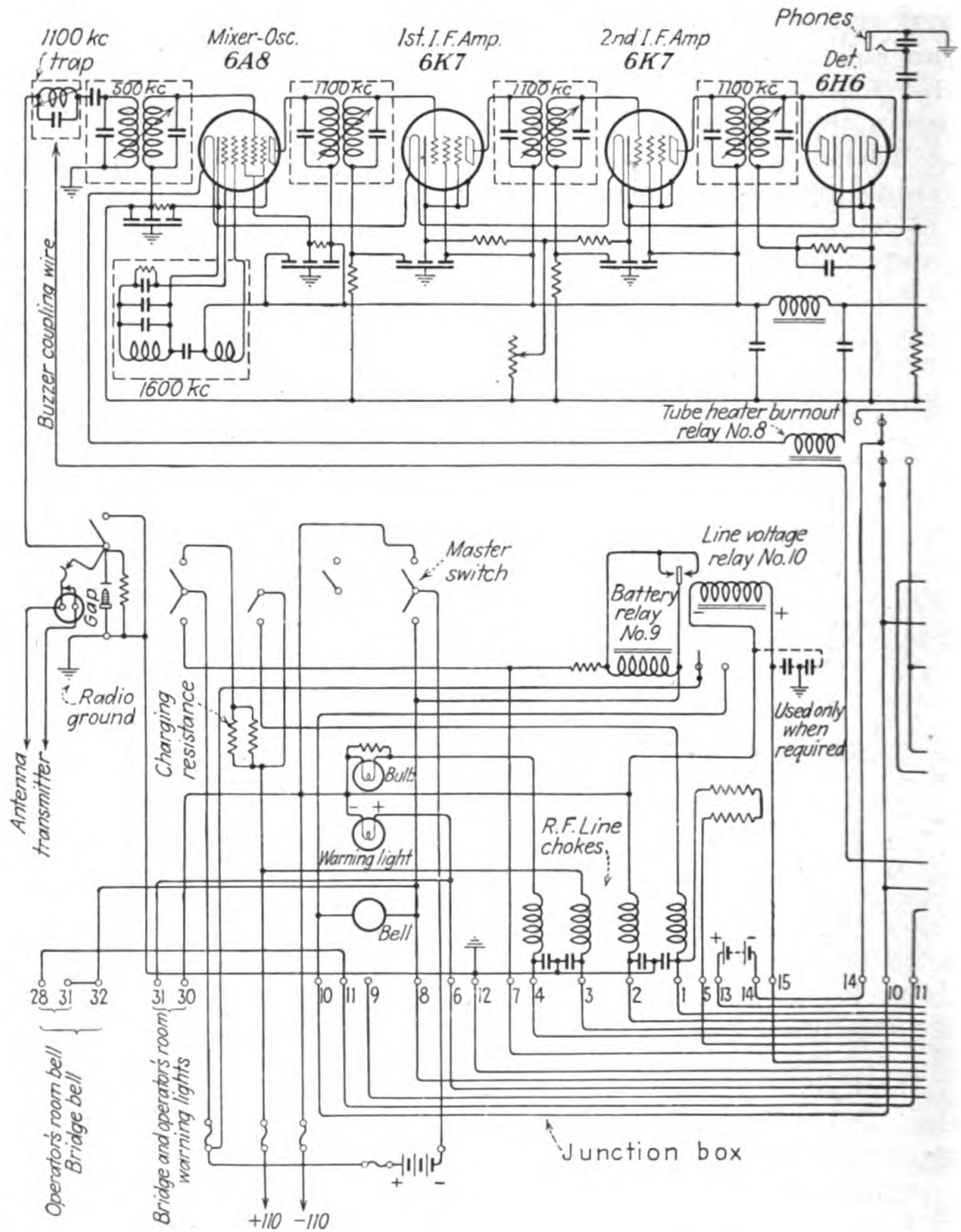


FIG. 15-2.—RMCA Model



from this oven is also used to maintain the component units of the auto alarm dry under marine conditions.

To the right of the oven, there is located the stepping relay. This relay advances one position each time a correct dash and space are received. When the stepping relay reaches the fourth position, after four correct dashes *and* spaces, the bells are energized.

There are four relays mounted beneath the oven. The first relay to the left is the radio relay, which is actuated by incoming signals as explained later. The next relay to the right is the filament-burnout relay and is used to ring the warning bells in case the filament of any vacuum tube should burn out. The next relay to the right of the filament-burnout relay is known as the bell-ringing relay. This relay closes upon receipt of an alarm signal and stays closed, causing the bells to ring continuously until the reset button is depressed. The next relay (underneath the stepping relay) is known as the auxiliary relay. The function of the auxiliary relay is explained further in this text.

The reset push button will be seen below the radio relay. This push button is used to stop the bells from ringing after the correct alarm signal has been received. To the right of the reset button, there is mounted a 0 to 15 direct-current milliammeter and below this meter a current-selector switch. Positions 1, 2, and 3 of the current-selector switch are used to read, respectively, the plate currents of selector tubes 1, 2, and 3. Position 4 of the current switch will permit the milliammeter to read the current through the coil of the radio relay. Position 4 is to be used, as hereinafter described, when adjusting the sensitivity control for optimum setting. Position 5 of the current switch is not used.

A test buzzer is mounted between the two meters. This buzzer is actuated by means of the test button so that a local signal may be induced into the auto-alarm receiver for testing overall operation. To the right of the buzzer, there is located a 0 to 150 direct-current voltmeter and beneath this meter a voltage-selector switch. Position 1 of the voltage switch will permit the voltmeter to read grid charging voltage from the voltage-regulator tube. Position 2 of this switch reads bias voltage on the grids of selector tubes 1 and 2. Position 3 reads bias voltage on selector tube 3. Position 4 indicates the heater or filament voltage across all tubes, and position 5 permits the shipboard line voltage to be read.

Typical readings of the milliammeter and the voltmeter for average shipboard conditions are given further in this text.

A sensitivity control is mounted beneath the test buzzer. This control adjusts the amplification of the radio receiver so that the optimum setting for the prevailing noise level may be obtained.

A push-button switch to temporarily disconnect the bridge and operator's room bells is provided at the left of the current switch. This switch

may be used by the operator to keep the bells from ringing during routine checking of the auto alarm.

A jack for the telephone receivers is mounted below the test button. Incoming signals may be monitored in this manner.

d. Operation.—The radio-receiver circuits of the auto alarm utilize a five-tube superheterodyne circuit which is shown in the schematic diagram. The antenna circuit after passing through the master switch connects to a tuned trap circuit (mounted back of the panel) which is adjusted at the factory for a frequency of 1,100 kilocycles. This is the intermediate frequency of the receiver, and the trap circuit is provided to suppress interfering signals having a frequency of 1,100 kilocycles. After passing through the trap circuit, the incoming signal is connected through a small condenser (50 mmf.) to a pair of broadly tuned circuits, which are adjusted to respond to 500 kilocycles plus or minus 12.5 kilocycles. In other words, signals having a frequency from 487.5 to 512.5 kilocycles are accepted. The first tube in the radio receiver is a type 6-A-8 mixer-oscillator. The oscillator portion of this tube is connected to a circuit which oscillates at a frequency of 1600 kilocycles. This 1,600-kilocycle energy is mixed with the incoming 500-kilocycle signal and produces in the plate circuit of the 6-A-8 the intermediate frequency of 1,100 kilocycle.

The 6-A-8 mixer-oscillator tube is followed by two stages of intermediate-frequency amplification, each stage using a 6-K-7 pentode amplifier tube. The intermediate amplifier uses a total of six tuned circuits which are so coupled to enable the incoming signal to vary between 487.5 and 512.5 kilocycle, without attenuation.

The fourth tube in the radio receiver is a type 6-H-6 diode detector. This tube has two plates which are connected in parallel and two cathodes which are connected in parallel. The radio signal, now at intermediate frequency, is rectified in the 6-H-6 detector stage and produces a direct-current voltage which appears across a 1-megohm resistor connected between the cathodes and one side of the third intermediate-frequency transformer secondary. This direct-current voltage from the diode stage is applied as a negative voltage to the grid of the fifth tube in the receiver, type 1611, which is known as the radio-relay tube. The relay tube has connected in its plate circuit the coil of the radio relay. Any incoming signal between 500 and 90,000 μ v, and within the specified frequency band, will actuate the armature of the radio relay. The type 1611 relay tube, in the absence of signals, has a steady current (about 7.5 ma.) flowing through its plate circuit. This current is reduced upon the receipt of a signal. This relay then initiates the timing action of the selector tubes in a manner to be described below.

An auto-alarm selector to operate efficiently with the international alarm signal, and to reject interfering signals, must perform three main functions. It should reject signals having a duration less than approxi-

mately 3.5 sec. It should reject signals having a duration greater than 4.5 sec. It should also be designed to recognize spaces between signals provided these spaces do not exceed 1.5 sec. In the model AR-8600 auto alarm, three selector tubes, with appropriate relays, are used.

As pointed out above, correct incoming signals will lower the plate current of the 1611 relay tube, causing the armature to make a contact. This applies a positive voltage to the grid of number 1 selector tube, type 1611, through a suitable resistance capacity network. This network causes a time delay so that no plate current will flow in the No. 1 selector-tube plate circuit until approximately 3.5 sec. have elapsed. At the end of this time, the plate current of selector tube 1 energizes the coil of the first selector relay and closes its contacts. These contacts then energize the "notch" coil of a stepping relay, which advances this latter relay one position. At the same time that the notch coil on the stepping relay is energized, voltage is also applied to the coil of the auxiliary relay. One pair of contacts on this auxiliary relay energizes the grid of the second selector tube, type 1611, which also uses a resistance capacity network in its grid circuit. If the incoming signal lasts for more than 4.5 sec., current will flow in the plate circuit of the second selector tube and will energize selector relay 2. This in turn will cause contacts to close on selector relay 2, which will energize the "restore" coil on the stepping relay. When the signal ceases, under these conditions, the stepping relay returns to its zero or starting position.

From the foregoing, it may be seen that signals having a duration between 3.5 and 4.5 sec. will cause the stepping relay to advance one position. It is now necessary to provide means for checking that the spaces between dashes are not excessive. This is accomplished by means of the third selector tube, type 1611, and the third selector relay. The contacts on selector relay 3 also energize the "restore" coil of the stepping relay. Spaces are checked as follows. At the end of any dash lasting between 3.5 and 4.5 sec., the auxiliary relay coil is deenergized and a pair of back contacts apply voltage to the grid of selector tube 3 through a resistance capacity network. After a time interval (approximately 5 sec.), plate current begins to build up in selector tube 3. However, if any subsequent dash after the first one is completed within 3.5 sec., the auxiliary relay closes again deenergizing selector tube 3. If the second or subsequent dashes are not completed in time, selector relay 3 closes, energizing the "restore" coil on the stepping relay.

The above explanation of selector operation may be somewhat difficult to understand at the first reading. However, if the auto alarm is operated with the test buzzer and the action of the various relays observed, as explained further, it is possible to secure a clear understanding of the overall operation.

A voltage-regulator tube, type 1611, is used in this auto alarm. The purpose of this tube is to supply a regulated source of voltage for the grid

circuits of the three selector tubes. Constants of the voltage-regulator circuit are designed so as to permit a small change in grid voltage to take place on the selector tubes under conditions of changing line voltage, so that timing of the selector circuits is not impaired.

The warning lights are used to indicate when heavy static or other interference impairs operation. Each time the stepping relay advances one position, a circuit is closed to the warning lights. These lights will remain lighted unless the static decreases or until a new adjustment is made on the sensitivity control.

e. Junction Box.—The following units are mounted in the junction box. Two sockets are located at the top of the unit into which are screwed the 6-volt battery charging resistors. Below these sockets are two 30-ohm enameled resistors which are used in series with the filament circuits of the tubes. There are four radio-frequency chokes below the filament resistors. One pair of these chokes is connected in series with the 110-volt line for filtering the power input to the auto alarm. The second pair of chokes filter the input to the oven in the auto alarm. Four small mica filter condensers are mounted below the chokes. To the left of the filter condensers, there is located a pair of fuse blocks for the incoming 110-volt line. Six-ampere glass fuses are used in these fuse blocks. To the right of the filter condensers there is a single fuse block which uses a 6-amp. glass fuse and which connects to the positive side of the 6-volt storage battery. A special *C* battery delivering 9 volts is mounted in the bottom of the junction box and held in place by means of a metal clamp. Numbered terminal blocks are provided for all incoming and outgoing circuits.

The following units are mounted on the inside of the door of the junction box: radio room bell and warning light; oven thermostat pilot light; line voltage relay; 6-volt battery relay.

A special 15-conductor lead-covered cable, color coded, is used to connect the radio receiver-selector unit to the junction box. A special 10-conductor color-coded lead-covered cable connects the junction box with the master switch. The incoming-bell and warning-light circuits, from the bridge and operator's room, as well as the incoming 110- and 6-volt circuits, are also brought into appropriate terminals in the junction box.

The line-voltage relay which is mounted on the rear of the cover of the junction box, to the left of the bell, is used to provide a warning whenever the shipboard line voltage is below or above predetermined values. If the line voltage falls below normal, the "low" or back contacts of the line-voltage relay close. This will cause all three bells to ring until the line voltage has been restored to its normal value. The same action takes place if the line voltage exceeds 120 volts direct current. To provide a warning in case the 6-volt storage battery approaches discharge, a second relay mounted to the right of the bell on the back

cover of the junction box is provided. The coil of this relay is connected across the 6-volt battery. If the battery voltage drops below approximately 4.5 volts, the bells will ring and will continue ringing until the battery voltage is restored to normal.

The high and low contacts on the line-voltage relay are used to short-circuit the coil of the 6-volt relay. In other words, low or high 110-volt line voltage supply or low voltage from the 6-volt battery will cause the 6-volt relay contacts to close, ringing the bells.

f. Master Switch.—The master switch is mounted on a base. A large Isolantite insulator ($7\frac{1}{8}$ in. high) is mounted on the base of the switch and is designed to withstand the full voltage from the radio-room transmitters. A contact arrangement is used at the top of the insulator to enable the antenna to be connected either to the auto alarm or to the other radio-room equipment. When the master switch is placed in the ON position, for auto-alarm operation, the antenna circuit is carried through the long arm on the switch to the terminal marked AA and thence into the auto-alarm receiver. A static leak and an adjustable spark gap are provided on the master switch between antenna and ground to prevent excessive voltages from reaching the auto-alarm receiver. The spark gap should be adjusted so as not to exceed a spacing of $\frac{1}{32}$ in. In the ON position, the master switch performs the following additional functions: connects positive 110-volt line to the auto alarm; connects positive and negative of the 6-volt storage battery to the auto alarm. When the master switch is placed in the OFF position, it disconnects the antenna from the auto-alarm receiver and connects the antenna to the other radio-room equipment. It also places the 6-volt storage battery on charge and in addition closes an interlock circuit in series with the main transmitter key. This interlock circuit is to prevent the main transmitter from being used unless the auto alarm has been taken out of circuit.

g. Bridge Bell and Warning Light.—The bridge bell and warning light are mounted in a metal box; the bell unit is designed to operate from the 6-volt storage battery. The warning light is a standard $7\frac{1}{2}$ -watt 120-volt lamp. The operator's room-bell and warning-light unit is similar to the bridge-bell and warning-light unit.

Adjustments to Be Made by Radio Operator before Going Off Watch

On the front cover of the auto alarm, there will be found printed instructions which read as follows:

Important Instructions

First: *Test the Alarm:* Close master switch. Set sensitivity control to approximately 40. Using radio-room clock, transmit alarm signal with test push button on auto alarm. Bells will ring after four correct dashes and spaces.

Second: *Adjust the Sensitivity Control:* Set scale at 0. Set current switch at 4. Meter will read about 7.5 ma. Turn sensitivity control to right until average meter reading due to noise, static, etc., is about 1 ma. less than maximum value. Listen

with phones. Incoming signals will cause signal relay to chatter slightly and meter reading to fall toward zero. If sensitivity is set too high for prevailing noise level, warning lights will indicate need for lower setting. Do not set sensitivity control lower than necessary as then weak distress calls may not be received.

When testing the auto alarm with the test buzzer and push button, the operator should observe that the milliammeter reading falls to zero or nearly so each time the test button is depressed. Close this button quickly several times and observe that the radio relay, whose armature click may be heard, follows the keying speed. Each time a correct 4-sec. dash and space are sent with the test buzzer, it may be observed that the stepping relay advances one position. If there is considerable radio interference or static during the time the alarm is being tested, it will be observed that the restore coil on the stepping relay is also energized, thereby preventing the stepping relay from advancing further. This condition will occur during testing whenever static or interference completely fills the spaces between dashes so that the normal auto-alarm signal is distorted. The position of the sensitivity control, during the test of the auto alarm, may be used as an approximate check on the sensitivity of the receiver and the correct performance of all tubes. If it is found necessary to advance the sensitivity control beyond approximately 40 to 50 on the scale, it may be inferred that one of the tubes in the radio-receiver part of the circuit is defective. After a little experience with the alarm, using the headphones plugged into the jack and by observing the operation of the radio relay on incoming signals, the operator may reach an approximate determination as to whether or not the receiver sensitivity is normal. In other words, on the average shipboard antenna it should not be necessary to advance the sensitivity control to the extreme right in order to make the radio relay operate with the average incoming signal.

A clear understanding of the results to be expected from various settings of the sensitivity control is necessary in order to adjust this control to the optimum or most favorable position. For example, if the sensitivity control is turned to the extreme right (100 on the dial) or nearly so, it may be found that the average noise level and static will cause the radio relay to hold over for long periods of time, or to chatter or vibrate steadily. When this occurs, the adjustment is not a favorable one, for not only will the warning light be illuminated frequently whenever static or noise persists for 3.5 sec. or more, but also a real alarm signal will be more apt to have its dashes prolonged and its spaces filled in, with such an adjustment. On the other hand, if the sensitivity control is adjusted too far to the left, that is toward zero on the scale, then only very strong signals will operate the auto alarm, and a distress call from a distant ship might be missed. The optimum adjustment will be found to be that which gives a reading on the milliammeter (with no incoming signals) which is approximately 1 ma. *less than* the reading obtained when the volume control is at zero. With such an optimum adjustment, the radio relay may close occasionally from short bursts of static or from ordinary code signals. The operator should keep in mind that if the sensitivity control is set too high the radio relay will vibrate constantly, which is an undesirable adjustment. The officers on the bridge will have instructions to summon the radio operator whenever the warning light on the bridge is illuminated for periods of 5 min. or more. When the sensitivity is set at 100 or maximum, a signal strength of approximately 200 μv will operate the auto alarm. At a dial setting of 50 (midscale), a signal of approximately 1,000 μv is required. At 0 setting of the sensitivity control, a signal strength of 20,000 μv is required.

Faults That Will Cause Sounding of the Audible Alarm

1. **False alarm.** Accidental combination of static or other interference may occasionally cause the stepping relay to advance to its fourth position, which will lock in

the bell-ringing relay and cause the bells to ring continuously. Bells will stop when reset push button is depressed on auto-alarm panel.

2. Filament burnout. If any one of the vacuum-tube filaments (heaters) should burn out, or if one of the 30-ohm series filament resistors in the junction box should burn out, the *filament-burnout relay* on the auto-alarm panel will have its coil deenergized, which will close the back contacts and cause the bells to ring. Bells can be stopped from ringing only by replacing the defective tube or resistor or by opening the master switch.

3. Low or high line supply voltage. If the 110-volt shipboard supply is reduced below normal or increased above 120 volts, the *line-voltage relay* in the junction box will operate, which will short out the coil on the 6-volt relay, causing the bells to ring. The bells will continue ringing until line voltage is restored to normal or until master switch is opened.

4. If the 6-volt battery approaches discharge and its voltage falls below about 4.5 volts, the back contacts will close on the *6-volt relay*, causing the bells to ring continuously until a suitably charged battery is placed in circuit or until the master switch is opened.

5. If the $\frac{1}{2}$ amp. fuse on the auto-alarm panel or any of the fuses in the junction box should be blown, the bells will ring continuously until the fault is corrected or unless the master switch is opened. The $\frac{1}{2}$ amp. fuse will blow in case of tube shorts or condenser breakdown in the receiver-selector unit.

Operation of Warning Lights

The purpose of the warning lights as explained previously is to provide a visual indication whenever prolonged static or other interference holds the radio relay open. After 3.5 sec., the stepping relay will advance one position and remain there as long as the interference is continuous. An auxiliary set of contacts on the stepping relay will close a circuit to the three warning lights to indicate this condition. The remedy is to readjust the sensitivity control to a slightly lower setting so that the stepping relay drops back to its normal or zero position.

Procedure to Be Followed When Alarm Bells Ring

1. If alarm bells ring momentarily, then stop ringing, and repeat this cycle frequently, the difficulty is most likely due to low, high, or variable line voltage. Go to the radio room, open the door of the junction box, and observe the line-voltage relay contacts. Also measure the line voltage by placing the voltmeter switch in position 5 on the auto-alarm panel. If the voltage is much below 100 volts, it will be observed that the line-voltage relay "left" contact is closed, causing the bells to ring. Higher than normal line voltage will cause the "right" contact to make on the relay, also ringing the bells. This condition of low, variable, or high line voltage should be brought to the attention of the proper ship's officer.

2. Alarm bells ringing continuously. Go to the radio room, and depress the reset button on the auto alarm. If this stops the bells from ringing, a pair of phones should be immediately plugged into the phone jack to determine if an alarm signal has been transmitted by a vessel in distress. If the bells do not stop ringing when the reset button is depressed, the fault may be low line voltage, high line voltage, low 6-volt battery supply, filament burnout, or blown fuses. Filament burnout may be immediately determined by placing the voltmeter switch in position 4, where a reading of 100 volts or more will be obtained instead of the normal reading of approximately 60 volts. A blown $\frac{1}{2}$ amp. plate fuse or 110-volt line fuse may be quickly determined by observing if any reading is obtained on the voltmeter with the switch in position 5. No reading will be obtained if these fuses are blown. If the 6-volt bat-

tery is low, this should be checked with the three-scale voltmeter carried in the radio room as a part of standard safety of life at sea equipment.

3. When troubles that cause the bells to ring continuously cannot be located quickly, it is desirable to disconnect the bridge bell and operator's bell temporarily to avoid undue annoyance to the ship's personnel. This may be done by removing the lead (blue with red tracer) which will be found on terminal 28 on the vertical right-hand terminal block of the junction box. After the trouble has been corrected, the operator should make certain that the lead to terminal 28 is firmly reconnected, and he should make a test with the bridge and the operator's room to insure that the bells are again functioning normally.

Log Entries

The following instructions with regard to log entries should be carefully observed as they are required by the FCC.

1. While the ship is at sea, the auto alarm shall be tested by means of the testing device supplied, at least once every 24 hr., the timing of the dashes to be made by reference to the sweep seconds hand of the station's clock. Bridge bell and warning light and operator's room bell and light must show correct operation when this test is made. A statement that the foregoing has been fulfilled must be inserted in the ship's official deck log and the radio log daily.

2. If the warning light is illuminated for a continuous period of 5 min. or more, the operator shall record in the radio log the time when he was called by the bridge, the time when he goes to the radio room to investigate the difficulty, the reason for the warning lights burning, and a statement as to the adjustments found necessary to restore normal operation.

3. If the bells ring, the operator should record in the radio log the time of the occurrence and the time when he arrives at the radio room to investigate the reason for the bells ringing. A record should also be made in the log to explain what caused the bells to ring, such as actual alarm, false alarm, filament burnout, low line voltage, low battery voltage, or blown fuses.

4. Vacuum-tube and battery information is to be entered in log. Each vacuum tube initially supplied in the auto alarm is dated at the time of installation. If any tube becomes defective, the operator should remove the tube and make an entry in the log to indicate the date the tube was removed and replaced and the tube socket from which it was taken. The defective tube should not be destroyed, but should be returned to the radio company responsible for the maintenance of the auto alarm. The new tube which is used to replace the defective tube should be dated by the operator. This may be done by scratching the date on the metal shell of the tube with the point of a knife or other sharp tool.

The 9-volt C battery (type D6BP) mounted in the junction box is provided with a label to record the date when installed, and also the date when it should be replaced. If for any reason the operator finds it necessary to replace the C battery with his spare C battery, he should enter this fact in the log, recording when the old C battery was taken out, when the new one was replaced and on the label of the new battery he should write the date when installed. The C battery should be replaced when it falls below 8.5 volts.

General Maintenance and Repairs at Sea

If normal operation of the auto alarm cannot be obtained, the radio operator should proceed as follows:

Important: Do not remove relay cover or oven cover on the auto-alarm panel or work with tools around any of the parts unless the master switch is in the off position.

1. Check with three-range radio-room voltmeter to determine if the 110-volt line voltage and 6-volt battery power exists across the appropriate input terminals in the junction box. If correct readings are obtained, make similar measurements across the proper terminals of the receiver-selector unit.

2. Make certain that all leads on the junction-box terminals from numbers 1 to 32 are tight and making good connections.

3. Relay contacts should be checked and cleaned, if necessary, to insure proper contact. To clean contacts, use the special burnishing tool which is furnished, taking care not to remove too much contact material with the burnisher.

4. If defective tubes are suspected, they should be replaced *one at a time*, starting with the 6-A-8 tube, always returning good tubes to the same socket from which they were removed. This will avoid confusion in locating a defective tube. Type 1611 tubes may be checked for emission by placing them successively in the second socket from the left in the lower row of tubes. This is the radio-relay tube socket, and the plate current of this tube may be read by the milliammeter with the switch in position 4. Normal tubes with 100 volts line should show a plate current with no incoming signal of approximately 7 ma. or more. When checking tubes, all tube sockets must be filled, otherwise bells will ring.

5. Each selector circuit may be checked by sending a test signal through the auto alarm and successively placing the "current" switch in position 1, 2, and 3. In position 1 after a long dash, a current of approximately 8 to 10 ma. will be obtained. In position 2 after a long dash, a similar value will be obtained. To check selector 3, place the switch in position 3, send a 4-sec. dash with the test buzzer and then observe after about 5 sec. that the meter reads momentarily a value of approximately 6 ma. The third selector tube shuts off its own plate current after it checks a space, and for this reason only a momentary meter reading will be obtained.

6. It is possible to check various voltages in the junction box and on the various component units back of the auto-alarm panel by referring to the schematic diagram and by using the three-range voltmeter which is carried in the radio room. Such a voltage analysis will enable the operator to determine if open circuits or poor connections exist in various parts of the circuits.

7. The switch contacts on the master switch should be checked occasionally to insure that they are making good connection, removing any corrosion or oxidation which may have taken place.

8. Normal operation of the oven heater will be indicated by intermittent operation of the small pilot light mounted on the back of the junction box cover. This pilot light is provided to enable the radio operator to determine that the oven circuit is operating normally whether or not the auto alarm is on watch.

9. If for any reason the auto alarm 6-volt battery becomes discharged, the operator should substitute one of the radio room 6-volt storage batteries temporarily. The auto-alarm battery should then be placed on charge from the standard radio room A battery charger. The operator should determine why the auto-alarm battery became discharged. The auto-alarm master switch is arranged to place the 6-volt battery on charge at a rate of approximately 2 amp. whenever the master switch is in the off position. This charging rate is sufficient to keep the alarm battery fully charged if the alarm is "on watch" for a period of 18 hr. daily. In other words, 6 hr. charging in each 24 hr. will keep the battery in good condition. If either or both battery charging resistors at the top of the junction box should become defective, standard 110-volt 100-watt lamps may be used as a substitute.

10. When replacing the 9-volt C battery, make certain that the green lead connects to the negative terminal and the brown lead to the positive terminal. No current is taken by the C battery, therefore if early C battery replacement is necessary

look for shorts or leakage. A voltmeter connected in *series* with one of the *C* battery leads should show no reading for normal operation.

11. If plate current is obtained through each selector relay as explained under 5 above and the stepping relay does not operate, inspect the contacts on the selector relay in the oven. Remove oven cover screws and carefully withdraw the oven cover *straight out* to prevent breakage of the thermometer. Relay contacts may now be examined and cleaned if necessary.

12. Note that the 6-volt storage battery has two fuses in the positive side of the circuit, a 6-amp. glass fuse in the junction box and also an external 10-amp. fuse installed near the battery. Short circuits in the 6-volt circuits in the auto alarm or junction box will normally cause the 6-amp. glass fuse to blow. Short circuits in the wiring to the warning bells will cause blowing of the external 10-amp. fuse. This arrangement allows the warning bells to ring when the 6-amp. fuse is blown. Both fuses should be inspected in case of trouble. Always use the specified ratings when replacing fuses.

13. The line-voltage relay will also cause the bells to ring if the polarity of the 110-volt shipboard line is reversed. The voltmeter on the receiver-selector unit in switch position 5 will also indicate this condition by reading in the reverse direction.

Typical Readings of Current and Voltage for Normal Auto-alarm Operation

The following readings are based on an average line voltage of 100 volts. Higher line voltages will give slightly higher readings.

Current Switch

- Position 1. First selector relay closes at approximately 4 ma.
- Position 2. Second selector relay closes at approximately 6.5 ma.
- Position 3. Third selector relay closes momentarily at approximately 6.5 ma.
- Position 4. Signal relay plate current is 7.5 ma. with no incoming signal. With signals, lower values, down to zero, will be obtained.
- Position 5. Not used.

Voltmeter Switch

- Position 1. Grid charging voltage 52 volts.
- Position 2. Grid bias on selector tubes 1 and 2, 29 volts.
- Position 3. Grid bias on third selector tube, 29 volts.
- Position 4. Heater voltage 60 volts.
- Position 5. Ship's line voltage.

When going off watch, the operator should always leave the "current" switch in position 1 and the "voltage" switch in position 5. If the current switch is left in position 4, the milliammeter will follow all incoming signals, causing unnecessary wear and tear on the instrument.

Testing Auto Alarm under Severe Static Conditions

Occasionally when static is very severe the sensitivity control cannot be advanced far enough to permit the test buzzer to actuate the receiver without causing the radio relay to "block" from the static. To test the alarm under these conditions, place a temporary short circuit between the *AA* terminal and ground terminal on the master switch. After the test, the short circuit should be removed and the sensitivity control adjusted to optimum for the prevailing noise level.

Understanding Selector Action by Observing Relays

1. Transmit "V"s or other code signals with test buzzer. Radio relay will follow keying, and milliammeter in position 4 will show a lower reading each time buzzer is operated. No other relays will operate.

2. Transmit one 4-sec. dash. Radio relay will operate instantly and after 3.5 sec. No. 1 selector relay in oven will close, auxiliary relay will close, "notch" coil will be energized and stepping relay will advance one position. This checks if dash is long enough.

3. Transmit one dash of 5 sec. or more. Same action as under 2 above will take place and in addition No. 2 selector relay in oven will close and "restore" coil on stepping relay will be energized. When long dash is broken, stepping relay will return to zero or normal position. This checks overlong dashes.

4. Transmit one 4-sec. dash to advance stepping relay one position and then break this dash. After approximately 5 sec., "restore" coil will click and stepping relay will return to zero. This checks spaces.

5. Transmit four correct 4-sec. dashes separated by 1-sec. spaces and watch the stepping relay move up with each dash, finally causing the bell ringing relay to lock in when the fourth dash is broken. Note that each dash, including the fourth dash, must be followed by a space to lock in the bell ringing relay. If the fourth dash (or any other dash) is too long the restore coil is energized on the stepping relay.

Preventing Overcharge of 6-volt Battery

When the ship is in port or dry dock or if the auto alarm is in use for only a few hours each day, the 6-volt storage battery may become overcharged. To avoid this use one charging resistor if the alarm is in use only a short time daily. In port or in dry dock, remove both charging resistors by unscrewing from sockets.

2. MACKAY AUTO ALARM 101-A. *a. General Description.*—The Mackay auto-alarm system consists of receiving and selecting apparatus located in the radio room, alarm bells and warning lights located on the bridge and in the radio room, and a third alarm bell located in the radio operator's cabin. The auto alarm is placed in service by the radio operator during such times as he is not on watch and the vessel is under way. The alarm bells are intended to call the operator to the radio room when an alarm signal is received or when the auto-alarm apparatus refuses to function properly.

Upon receipt of an alarm signal, the auto alarm will cause the bells to ring. On the sounding of such an alarm, steps should be taken to inform the operator immediately so as to guard against the possibility that he may not have heard the alarm. The ringing of the bells also serves to indicate when the auto-alarm receiving equipment becomes inoperative owing to a failure of power, or to the burning out of a tube. Regardless of the reason for sounding the alarm, it can be stopped only from the radio room.

The Mackay Radio and Telegraph Company's auto alarm 101-A consists of the following units:

1. Auto alarm receiver 101-A.
2. Auto alarm selector 101-A.
3. Antenna switch.
4. Three alarm bells.
5. Two warning lights.
6. Auxiliary equipment, consisting of:
 - a. Two sets 24-volt storage batteries.
 - b. Charging equipment for above.
 - c. Receiver power supply unit.
 - d. Auxiliary 90-volt *B* battery.
7. Two instruction books.
8. Set of spare parts.

The power requirements for the equipment are:

- 1.4 amp. from the 24-volt batteries.
- 12 to 25 ma. from the power supply unit or from the 90-volt *B* battery.
- 1.7 amp. from the ship's 115-volt direct-current line for the charging of the batteries and for operation of the power-supply unit.

(1) *Receiver*.—It is the function of the receiver to accept all signals within the prescribed frequency band of 487.5 to 512.5 kilocycles modulated at least 30 per cent at frequencies between 100 and 2,500 cycles and transform those signals into such a form that they will operate the signal relay whenever those signals produce at the receiver input terminals a radio-frequency voltage of 500 μ v or more.

The receiver of the Mackay radio auto alarm is of the tuned radio-frequency type employing a single stage of radio-frequency amplification in which the tuning is fixed, followed by a detector, two stages of audio-frequency amplification, and a rectifier.

The receiver uses five tubes of the 6-volt heater type: one 6D6 as the radio-frequency amplifier, one 76 as a detector, two 76's as audio-frequency amplifiers, and an 89 as a rectifier.

Referring to the schematic circuit diagram (Fig. 15-3), the heaters of tubes VT-1 to VT-4 are in series and are then connected in parallel with the heater of tube VT-5 and its series resistor. The total heater current passes through the winding of the low-resistance relay *A*, which operates and opens the alarm-bell circuit through its front contacts 1 at the same time closing its back contacts 2, thereby completing the plate-supply circuit to the receiver. This relay is adjusted to operate when full heater current passes through its winding. The burning out of any heater will reduce the current to a value that will release the relay, closing the contacts which complete the alarm-bell circuit, thus indicating that the equipment is out of order.

The antenna feeds the first two resonant circuits through the small coupling condenser C_5 , a resistor R_1 being connected between the antenna and ground to drain off static charges accumulated by the antenna. The two resonant circuits L_1C_1 and L_2C_2 are each tuned to 500 kilocycles and

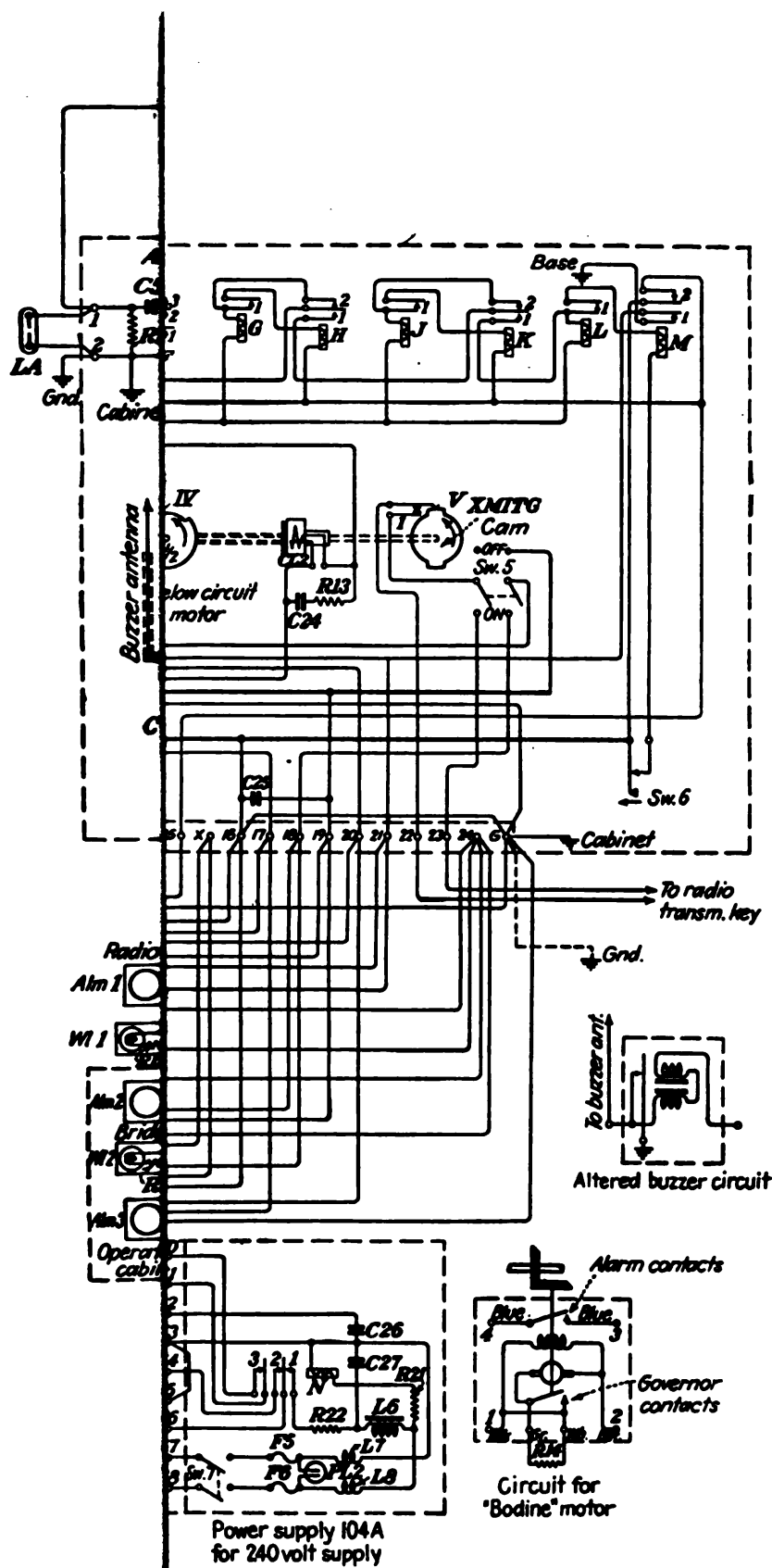
are overcoupled with each other sufficiently to produce two small humps, one on either side of 500 kilocycles. The second circuit feeds the grid of the radio-frequency amplifier tube VT_1 . This tube is, in turn, coupled to the detector tube by two similar circuits L_3C_3 and L_4C_4 . In this manner, the receiver is made to respond efficiently to signals within the frequency band of 487.5 to 512.5 kilocycles and to exclude signals outside this band in the manner specified by the regulations. The resonant circuits are adjusted to proper resonance before leaving the factory, except for the first, or antenna circuit, which is adjusted at installation. The radio-frequency transformers use air-core coils which are tuned by air dielectric condensers in order to maintain proper resonance under various conditions of temperature and humidity.

The detector VT_2 employs grid rectification and feeds the audio-frequency signals to the rectifier tube VT_5 through two audio-frequency amplifier tubes VT_3 and VT_4 which are transformer coupled by T_3 , T_4 , and T_5 . The condensers C_8 , C_9 , C_{10} , and C_{11} , together with the broadly resonant circuit $L_5R_4C_{15}$, are for the purpose of providing a flat frequency characteristic to the audio amplifier over the frequency range of 100 to 2,500 cycles per second.

The rectifier tube VT_5 operates upon the principle of plate rectification. When a signal voltage is applied to its grid, its plate current increases from its low no-signal value to a higher average value sufficient to operate the signal relay B , which is included in its plate circuit. The value of this plate current is indicated by the milliammeter MA , which is mounted on the panel of the receiver unit. The condenser C_{18} , connected between the plate and cathode of the rectifier tube, serves to smooth out the current and prevent relay chatter. The contacts 1 of this relay control the operation of the selector, or timing unit. The condenser C_{19} and the resistor R_{11} are connected across the relay contacts to reduce sparking and radio-frequency interference in the receiver.

The sensitivity control R_6 is a potentiometer for controlling the screen-grid potential of the radio-frequency amplifier tube so that the sensitivity of the receiver may be adjusted between the limits of approximately 250 and 50,000 μv . This is made use of in adjusting the sensitivity of the receiver to the "optimum" value for the prevailing conditions of noise or static during periods of no-signal. A higher sensitivity would cause the signal relay to be energized by the noise or static for extended periods, during which time it would be incapable of further operation by signals.

A buzzer, with its controlling push button SW_2 of the non-locking type, is provided for the production of radio-frequency test signals. The output of the buzzer is coupled into the antenna circuit by means of the buzzer antenna, which is a short piece of wire from the buzzer to a point near the antenna lead. This antenna is adjusted to produce a radio-frequency input into the receiver of about 2,000 μv .



The switch SW_3 , also of the non-locking type, opens the circuit to the bridge and cabin bells when depressed so that those bells may be cut out of circuit when desired during routine tests.

The phone jack J connects a pair of headphones to the low-impedance winding of transformer T_3 , feeding the rectifier, so that the operation of the receiver may be monitored by ear.

All component parts of the receiver are mounted upon a formed metal chassis which is attached to the hinged door of the metal cabinet. The milliammeter, sensitivity control knob and scale, buzzer push-button knob, the bridge and operator's cabin-bell disconnect switch knob, and the monitoring phone jack are located on the front of the cabinet door. All parts are protected against the effects of temperature and humidity.

The grid, plate, and cathode circuits of the receiver are isolated from the grounded chassis and cabinet, except through by-pass or grounding condensers, so that the receiver may be operated from power supplies, which may or may not themselves be grounded.

(2) *Selector*.—It is the function of the selector to accept and register the correct auto-alarm signal, to sound the alarm, and to reject all other signals and atmospherics. It does so by measuring the length or duration of the signals as well as the spaces between the signals.

The selector of the Mackay radio auto alarm, shown in Fig. 15-3, consists of three motor-driven timing elements and a bank of counting relays. The timing elements are cams which operate contacts after a certain angular rotation. The motor, which rotates the cams, operates during all the time the equipment is "watching." It is shunt wound and is equipped with a governor in which centrifugal force opens contacts and places a resistance in series with the armature circuit, thereby maintaining the speed of the motor constant at 1,800 r.p.m. The motor, through a reduction gear, drives a slow-motion shaft at 6 r.p.m. On this shaft are two electromagnetic clutches, which, when energized, engage and rotate the cams. Two of these cams are integral with each other and are operated by one of the clutches. This clutch measures the length of the dashes. The second clutch operates the third cam and measures the length of the spaces between the dashes. The counting of the dashes is accomplished by a bank of relays connected to form a counting chain.

A release key of the push-button type, on the front panel of the unit is used to release the alarm-bell circuit after it has been set off by the proper sequence of alarm signals. It will not, however, release the alarm if the alarm has been set off through failure of the equipment, and this fact is made use of to differentiate between the receipt of an alarm and the ringing of the alarm bells through failure of the equipment.

(3) *The operation of the selector* will now be described in detail under the following conditions:

- (a) The first dash.
- (b) Dash too long.
- (c) Space after the first correct dash.
- (d) The second correct dash.
- (e) The third correct dash.
- (f) The fourth correct dash.
- (g) Operation through interference.

(a) *The First Dash.*—By the first dash is meant any dash that starts after an interval sufficiently long so that all the equipment is in its normal rest position. At the beginning of this dash, relay *B* in the receiver is energized by the plate current of the last tube of the receiver. Relay *B* in the receiver energizes relay *C* in the selector. The operation of relay *C* closes its contacts, and the magnetic clutch *CL*₁ is energized.

The cams $3\frac{1}{2}$ and $4\frac{1}{2}$ begin to revolve. Cam contacts I immediately open, but have now been bridged by contacts *C*₁, and relay *C* remains closed. If the dash does not last for $3\frac{1}{2}$ sec., then its termination opens relay *B*, breaking the circuit of relay *C*, and thereby opening the circuit of the magnetic clutch *CL*₁; the cams $3\frac{1}{2}$ and $4\frac{1}{2}$ then return to their zero position. Relay *C* cannot be energized again until the cam $4\frac{1}{2}$ has reached its zero position and allowed cam contacts I to close.

When a dash has continued for $3\frac{1}{2}$ sec., cam $3\frac{1}{2}$ operates cam contacts III, which operate relay *E*.

The closing of contacts *E*₁ places the winding of relay *E* in series with the winding of relay *F*, and both across the battery, except that winding *F* is short-circuited while the cam contacts III-2 are closed.

At the termination of the dash, provided its duration is between $3\frac{1}{2}$ and $4\frac{1}{2}$ sec., the relays *B* and *C* are opened and clutch *CL*₁ is released, thus opening the cam contacts III-2. Current now flows through relay windings *E* and *F* in series.

The closing of relay *F* energizes the magnetic clutch *CL*₂.

The closing of relay *F* also connects relay *G* into the circuit to receive the next impulse from cam contacts III-2 through contacts *F*₂ and *H*₂.

(b) *Dash Too Long.*—If any dash lasts more than $4\frac{1}{2}$ sec., cam $4\frac{1}{2}$ operates its cam contacts II and closes the circuit of the winding of relay *D*, which closes and remains closed as long as the dash continues, but opens when the termination of the dash opens relay *B*. Back contacts *D*₂ energize the warning lights.

(c) *Space After the First Correct Dash.*—The battery side of the circuit of relays *E* and *F* has two optional paths, one through the cam contacts IV-1 to *D*₂ and battery, and the other through contacts *C*₂ to *D*₂ and battery. One and one-half seconds after the termination of the dash, cam $1\frac{1}{2}$ opens its contacts, IV-1. If the next dash has not yet started, contacts *C*₂ are also open so that all counting relay circuits, including the circuit of relays *E* and *F*, are broken, thus placing all relays in their rest position. However, if a dash has started, contacts *C*₂ are closed and relays *E* and *F* remain closed. This dash, from the time it started, has caused cams $4\frac{1}{2}$ and $3\frac{1}{2}$ to be operated in the same manner as described for the first dash. If this second dash terminates or is interrupted at some time between the $1\frac{1}{2}$ - and $3\frac{1}{2}$ -sec. intervals required for the operation of cam contacts IV and III, respectively, then relays *E* and *F* are opened and the first dash is thereby uncounted or erased. It should be noted that the $1\frac{1}{2}$ -sec. interval may be occupied by interference, relay *C* and cams $4\frac{1}{2}$ and $3\frac{1}{2}$ returning to their zero position at the termination of every dot, dash, or static crash without erasing any counts.

(d) *The Second Correct Dash.*—This dash having started as described in the previous paragraph and having continued for $3\frac{1}{2}$ sec., cam contacts III are operated. Cam contacts III-2 close relay *G* as they did relay *E* for the first dash, while cam contacts III-1 release clutch *CL*₂. Cam $1\frac{1}{2}$ then returns to rest or zero position,

closing its cam contacts IV-1, thereby maintaining a closed circuit for the counting relays *E* and *F*, even though the dash stops and relay *C* opens. If this second dash does not last for more than $4\frac{1}{2}$ sec., it operates counting relays *G* and *H* in a similar manner to the operation of relays *E* and *F* by the first dash. After the cessation of the second dash, cam contacts III-1 close and start the $1\frac{1}{2}$ -sec. timer, whose contacts break the counting relay circuits if the third dash does not start within $1\frac{1}{2}$ sec.

(e) *The Third Correct Dash.*—This dash results in the setting up of counting relays *J* and *K* through the same sequence as that described for the setting up of relays *G* and *H* after the second correct dash.

(f) *The Fourth Correct Dash.*—The actions during the third space are the same as during the first and second spaces. When the fourth dash has lasted $3\frac{1}{2}$ sec., it sets up relay *L*. At the termination of the fourth correct dash, relay *M* is operated and rings the alarm.

(g) *Operation through Interference.*—The selector will operate to select the auto-alarm signal from a considerable amount of interference, caused either by other stations or by atmospherics, provided:

i. The interference does not combine with the desired signal so as to actuate relay *B* for periods in excess of $4\frac{1}{2}$ sec. duration.

ii. The interference does not completely fill in the interval between the dashes of the auto alarm signal.

The presence of interference immediately preceding or immediately following the dashes of the auto-alarm signal has the effect of lengthening those dashes. If the lengthened dash remains less than $4\frac{1}{2}$ sec. in duration, the selector will accept it as a dash of correct length. If lengthened beyond $4\frac{1}{2}$ sec. duration, it and any previous registered dashes will be rejected as described in paragraph (b).

Interference which exists during the interval between dashes of the auto-alarm signal, but does not completely fill that interval, will operate relay *B*, which, in turn, operates relay *C* and starts the rotation of cams $4\frac{1}{2}$ and $3\frac{1}{2}$ as for a dash, paragraph (a). If the interference ceases before the $1\frac{1}{2}$ -sec. period expires and before the end of the silent interval of the signal, relay *B* will open releasing relay *C*, thus returning cams $4\frac{1}{2}$ and $3\frac{1}{2}$ to their rest or zero position, ready to receive the next dash. Since cam $1\frac{1}{2}$ has not yet operated its cam contacts IV, any record of previous dashes existing in the counter will remain intact. Interference that completely fills the silent interval acts to prolong the preceding dash beyond its limit of $4\frac{1}{2}$ sec.

The transmitting cam together with its cam contacts V-1 and one pole of the SIG. TRANSMIT switch may be used in connection with a suitable keying relay to operate the ship's transmitter for the correct transmission of the auto-alarm signal. The other pole of the switch completes the motor circuit to battery removing the necessity of shifting the antenna switch.

There are auxiliary contacts on the motor governor which operate when the speed becomes too slow and operate the alarm bells.

Spark suppressors have been incorporated across the terminals of the two clutch windings to eliminate interference in the receiver from these circuits.

(4) *Antenna Switch.*—An antenna switch is provided for transferring the ship's main antenna from the normal ship radio equipment to the auto-alarm receiver and for putting the auto-alarm equipment into operation.

The blade of the antenna switch, insulated for high voltage, transfers the antenna. Auxiliary contacts, operated by the movement of the antenna blade, supply power to the receiver and selector units and also complete the circuit to the alarm bells.

No test whatsoever of the alarm equipment can be made without the antenna switch being closed on the auto-alarm position, the closing of that switch completing automatically the power circuits of the entire apparatus.

b. Auxiliary Equipment. (1) *Storage Batteries.*—This equipment is normally supplied with two sets of 24-volt storage batteries which supply power for the operation of the heaters of the receiving tubes, the timing motor and clutches, the counting relays, the alarm bells, and the warning lights. They are connected to the battery charger so that one set may be charged while the other set is being discharged. The normal drain from the batteries is 1.4 amp., each set of batteries being rated at 60 amp.-hr. capacity.

(2) *Battery Charger.*—The battery charger supplied with this equipment operates from the ship's 115-volt direct-current lines and charges the batteries at a 1.7-amp. rate. One four-pole double-throw switch is supplied on the charger panel by which the batteries may be alternately charged and discharged. The circuits of this switch are so arranged that the two sets of batteries discharge in reverse direction through the equipment, although both are charged in the proper direction. This is done in order to reverse the direction of current flow through the motor-governor contacts, thereby greatly reducing the tendency for those contacts to become pitted. A two-pole single-throw switch, with fuses, is provided for controlling the charging current from the ship's direct-current lines. Separate fuses are provided for the discharge circuits, a 6-amp. fuse for the alarm-bell circuit, and a 3-amp. fuse for the rest of the equipment. When operation is to be from a 230-volt direct-current line, the charger is equipped with an additional series resistor to maintain the proper charging current value.

(3) *Receiver Power Supply Unit.*—Plate circuit power for the receiver is obtained from a receiver power supply unit, which takes power from the ship's 115-volt direct-current lines and properly filters it for this use. A small toggle switch on the door of the unit is used to control the current applied to the unit. The pilot light, also on the door, indicates when the unit is in operation. The circuits are protected by 1-amp. fuses within the unit. A relay is provided which is so adjusted and arranged that it will transfer the receiver circuits for operation from the auxiliary 90-volt dry *B* battery, should the voltage of the ship's direct-current line fall below approximately 70 volts. When this transfer to *B*-battery operation is made, this relay also completes the circuits of the warning lights on the bridge and in the radio room to indicate both that operation is from the auxiliary batteries and that the charging of the 24-volt storage battery has stopped or is greatly reduced through this lowering of the line voltage.

(4) *Auxiliary 90-volt B Battery.*—Each installation is normally provided with a 90-volt dry *B* battery for use, as explained above, during such times that the ship's 110-volt direct-current power is not available in the

radio room. This battery consists of two 45-volt units of the type generally available for this use.

c. Operating Instructions. (1) *How to Start Auto-alarm Equipment.*—Close four-pole switch on battery charger to position to discharge desired battery. Turn power supply unit on, as indicated by the red pilot light on the cover. Shift the auto-alarm antenna switch to the auto-alarm position, seating the blade completely in place, thereby transferring the antenna to the auto-alarm receiver and completing the power circuits to the equipment. Close the two-pole switch on the battery charger, thus charging the second 24-volt battery. After approximately 30 sec., in order to allow the tube heaters to warm up, the auto alarm should be in operating condition.

Note: The charging rate has been adjusted to such a value that the batteries will be returned to the fully charged condition if they are charged 1 hr. for every hour of discharge. The battery on discharge should be alternated every 24 hr. rather than each time the equipment is placed on watch, unless this only occurs once per day, as this will result in a more equal division of operating time between the two sets.

(2) *How to Stop Alarm Bells.*—If the alarm bells are ringing because of the reception of a *true-alarm signal*, or from a false-alarm signal, the bells will be stopped when the release key on the selector-unit panel is pressed. If, however, the bells do *not* stop ringing when this button is pressed, their ringing is caused by some failure of the equipment and they will only cease when the failure is remedied or the auto-alarm equipment is turned off. The failures of the equipment which will cause the bells to ring include:

- (a) Burning out of a vacuum-tube heater.
- (b) Storage-battery voltage becoming too low.
- (c) Selector fuse on battery charger blown or the 24-volt circuit to auto-alarm equipment open.
- (d) Motor stopped or running too slow.
- (e) Vacuum-tube heater circuit or 24-volt circuit to receiver open.
- (f) Ground on alarm-bell circuit.

(3) *How to Stop Auto-alarm Equipment.*—Shift auto-alarm antenna switch from the auto-alarm side to the opposite side, thus connecting the antenna to the normal radio equipment. Turn off the receiver power supply unit. Open two-pole switch on battery charger to stop charging of battery unless it becomes necessary to continue charge for any reason.

(4) *General Operating Notes.*—Allow approximately 30 sec. or more after starting the auto-alarm equipment for the heaters of the tubes to warm up and the receiver thereby to become operative.

When testing the alarm with dashes from the buzzer, headphones should be used to monitor the receiver in order to note any interference which may be present. With no interference present, the bells should ring after four correctly timed dashes have been applied to the receiver.

During times of interference, it may require more than the minimum of four dashes to operate the bells, depending upon the manner in which the interference combines with the alarm signal to spoil the timing of the latter.

This receiver has been designed for the specific purpose of operating a relay from the received signals. It was *not* designed for the aural reception of signals. Therefore, the signals heard in the headphones during monitoring will have a peculiar sound or quality, making the receiver somewhat inefficient for headphone use. Do not be misled, therefore, in judging its capabilities by what you hear in the phones.

It should be noted that this receiver, in accordance with specifications, is fitted with a weak signal square-law detector (VT_2), which requires a modulated wave for its operation. Hence, this detector cannot operate upon the receipt of *C-W* (type A1) emission.

d. Maintenance.—In order that electrical and mechanical equipment operate at its maximum efficiency, it must be given attention periodically. The auto alarm is such a piece of equipment and should be cared for in the following manner:

(1) *General.*—The entire equipment should be kept *clean* and free from dust and foreign matter. All connections and mounting screws should be checked periodically for tightness. Spares, when used, should be replaced as soon as possible. All routine tests should be faithfully performed with particular attention given to evidence of failure of any kind.

(2) *Tubes.*—The operator in charge of the equipment should make himself acquainted with the normal response of the receiver by means of headphones plugged into the phone jack in order that he may detect any subsequent weakening of the tubes in the receiver. In addition, he should note the setting of the sensitivity control at which the milliammeter on the receiver panel averages a 5 ma. reading on test buzzer signals when the line voltage is normal for the particular installation. Further check may be obtained by setting the sensitivity control in the above manner and then substituting a new tube in each position in rotation, noting the milliammeter reading for each substitution. A pronounced increase in reading will then indicate when a weak or defective tube has been replaced.

(3) *Relays.*—All relays and contact springs should be handled with care so as not to change their adjustment or tension. All relay and timing cam contacts should be polished with the burnishing tool supplied for this purpose once a month, or oftener should this prove desirable for particular installations.

(4) *Motor.*—The motor is equipped with self-oiling ball bearings and a reduction gear running sealed in grease. It should not require oiling except after extended use and then only by competent servicemen from the service depots. *Never use any kind of abrasive whatever on the commutator or governor rings.* Should they require any attention, merely *clean them* with a cloth, together with the brushes and the brush holders. A solvent, such as a small amount of carbon tetrachloride, benzine, or alcohol, may be beneficial in some cases. However, care should be taken not to scratch the contact surface of the copper. If the governor contacts become pitted, they may be smoothed by a very fine file or a fine sandpaper, followed by a thorough burnishing with the burnishing tool to regain their polished surface.

(5) *Receiver Power Supply Unit.*—This unit requires no maintenance except the switching relay, which should be burnished in the manner specified above.

(6) *Storage Batteries.*—The storage batteries of this equipment are similar to any other storage batteries used with radio equipment and should receive the same attention. They should be kept clean, filled with distilled water, and properly charged. The charging rate has been set at 1.7 amp., which is the correct value to recharge the batteries in 1 hr. for each hour of discharge. They should be given a periodic overcharge in order to equalize the batteries and keep them in proper condition.

(7) *Dry B Batteries.*—The voltage of the dry *B* batteries should be checked each week *under load*, that is, after being placed in operation by leaving the power supply unit switch off for a period of 5 min. Batteries should be replaced with fresh ones as soon as practical after their voltage, as measured above, drops to 75 volts.

e. Correction of Faults.—The following is an outline of faults that might occur in the auto-alarm equipment, together with methods of correcting them. This outline is not intended as a complete listing, but merely as a guide to aid in the servicing of this equipment and maintaining it in operation.

1. *No signals from receiver.* Ship's direct-current reversed, thus placing negative side on tubes' plates. Check by turning power supply unit off and noting action of voltmeter with its switch held on *B*. Radio-frequency amplifier tube grid lead off or grounded. Dirty contacts on relay *A*.
2. *Signals in phones but no relay action.* Defective 89 rectifier tube. Shorted condenser, *C*₁₁. Open milliammeter.
3. *High noise level locking up relay.* If noise stops when antenna is disconnected, source is external to equipment and should be located and corrected, if possible. If noise continues, source is in equipment or from ship's direct-current line. If noise continues when receiver power supply is turned off and two-pole switch on battery charger opened, the source is in equipment. Check all connections for their tightness, clean motor commutator and brushes.
4. *Defective audio transformer.* Temporary repairs may be made either by jumping out the defective stage or by utilizing the remaining good winding of the transformer by using it as choke and reconnecting the stage as an impedance-coupled stage.
5. *Signal relay operates but no selector operation.* See that dash cam returns against its back stop and completely operates cam contacts below the cam. If necessary, increase cam return spring tension by loosening the three screws holding clamping ring around the knurled shoulder next to motor shaft coupling, and then rotate knurled shoulder counterclockwise a portion of a revolution, again tightening the clamping ring screws.

Examine these bottom cam contacts and see that they are "making" properly. These contacts must close before the signal relay can operate relay *C* and, in turn, the dash clutch. See description of operation under heading *The First Dash*.

6. *Space cam does not operate.* Contacts 111-1 of 3½-sec. cam dirty, or not closing. Back contacts of relay *M*₂ dirty or not making. Contacts of relay *E*₁ dirty or not making. Clutch collector ring brushes dirty or not enough tension.
7. *Counting relay operation OK, but bells do not ring.* If relay *M* does not lock up, release key may be stuck. If relay does lock up, contacts *M*₁ may be dirty, alarm fuse on battery charger blown.
8. *Alarm does not ring after four test dashes.* When the alarm receiver is connected to an antenna, external signals may combine with the test signals in

such a manner that the combination will act to spoil the timing of the test signal. The headphones should be worn during test of the auto-alarm equipment in order to make certain that when additional dashes, beyond the normal number of four, are required it was because of the presence of interference.

9. *Erratic registering of correctly timed signals.* If some correctly timed dashes may be registered in the counter while others are not, with no interference present, check motor speed, relay *B* contacts, relay *C* contacts, dash clutch collector rings and brushes for proper operation.
10. *Motor speed suddenly much too high.* Governor contacts pitted and welded closed, governor contacts shorted out of circuit.
11. *Motor speed much too slow.* Governor contacts dirty, governor brushes dirty, stuck in holder, worn too short.
12. *Alarm bell does not operate.* Remove from housing and burnish contacts thoroughly.
13. *Buzzer does not operate.* Dirty or burned contacts, contacts out of adjustment, series resistor open, buzzer button not making proper contact. Buzzer is adjusted by screw at bottom, backing it out at least one-half turn from point where it merely clicks, until a smooth note and steady meter reading is obtained.
14. *Alarm bells operate because of equipment failure.* The source of the trouble can be located most easily through the following procedure:
 - a. Observe voltmeter; if no indication of voltage on positions $-A$ or $+A$, check selector fuse on battery charger.
 - b. If voltmeter indicates some voltage on above position, note whether it is normal 24-volt reading. Battery may be nearing complete discharge.
 - c. If voltmeter shows normal 24-volt reading, open selector cabinet and note whether motor is operating at normal speed.
 - d. If so, open receiver cabinet and observe whether relay *A* is operated, indicating the heater circuit complete.
 - e. If above steps do not indicate location of failure, check bell circuits for grounding by removing the bell leads, one at a time, from their terminals; a ground on any one of these leads will cause all bells to operate.
 - f. If the failure still remains, replace above leads and then remove lead from terminal 5. If bells continue to operate, trouble is in receiver alarm-bell circuit wiring or relay *A*. If failure stops, trouble is in selector alarm-bell circuit wiring, or in motor alarm contacts, or in relay *M*.

A similar process of elimination, after a study of the circuit diagram, will assist in locating the source of any trouble that might appear with this equipment. The bridge and operator's cabin bells may be removed from the circuit and thereby prevented from ringing and causing unnecessary disturbance during the above tests (except for the required tests) by removing the leads from terminals 3 and 4 in the receiver cabinet.

15. If it becomes necessary to operate the auto-alarm receiver from the auxiliary *B* battery for any reason, the circuit from the power supply unit relay to the warning lights should be opened by removing the lead from terminal 50 in the power unit, taking care that the lead does not become grounded. This lead should be reconnected when operation from the power unit is resumed.

f. Miscellaneous Information.—(1) *To Transmit an Auto-alarm Signal.* Upon receiving orders from the captain, or other authorized officer

of the vessel, to transmit an auto-alarm signal (which precedes the SOS distress signal) proceed as follows:

Place the ship's radio transmitter in operating condition on 500 kilocycles, adjusted for a broad signal (in the manner called for in the regulations for transmitting a distress signal), close the four-pole switch on the auto-alarm battery charger and turn on the switch marked SIGNAL TRANS, on the auto-alarm selector panel. This starts the selector motor independently of the rest of the auto-alarm equipment and completes a circuit to the wedge-type plug which is inserted in the hand key. Contacts in the selector will then operate the transmitter keying relay to transmit correctly timed alarm signals of 4-sec. dashes and 1-sec. spaces between dashes. *To stop transmission* it is only necessary to remove the wedge plug and turn off the Signal Transmit switch on the selector panel.

(2) *NOTE:* The transmitting contacts in the selector unit may be used only to key a transmitter through the medium of a relay. These contacts are not designed to handle over 50 to 75 ma. at 110 volts and should never be used to handle any higher power. This feature of the auto-alarm equipment, therefore, will only be wired in on vessels provided with a suitable keying relay.

CHAPTER 16

MARINE RADIO DIRECTION FINDERS

Since the First World War, the marine radio direction finder has been in common use aboard ship. More recently the law made it compulsory for passenger vessels of 5,000 gross tons or over to be equipped with an approved type of radio direction finder. Two such approved direction finders, which are in common use aboard American vessels, will be described in this chapter.

Rule 8.191 of the FCC requires that the radio direction-finder apparatus, or radio compass, installed on a passenger vessel of 5,000 gross tons or over, in compliance with the requirements of the law, shall be capable of efficiently receiving signals (at least types *A2* and *B* emissions) on any frequency between 285 and 515 kilocycles, shall be accurately calibrated for the purpose of taking bearings from which the true bearing and direction may be determined, and shall be available for use whenever the vessel is being navigated outside a harbor or port.

Rule 8.192, also promulgated by the commission, requires that new installations of direction finders made after Jan. 1, 1940, shall be capable of receiving signals on types *A1*, *A2*, and *B* emissions.

In operation, the incoming signal from a radio beacon (or from another ship) is picked up by the rotatable shielded loop, which is mounted in ball bearings above the deck on a suitable pedestal. This signal is made audible or visible to the navigator through a modern highly sensitive radio receiving set.

16.1. Applications of the Radio Direction Finder.—There are various ways of applying the radio direction finder to navigational purposes. The radio direction finder may be installed on a vessel or aircraft and bearings taken on any source of signals. The advantage to the marine navigator of being able to do this himself in times of thick weather at sea is apparent. Likewise, when the instrument is installed in an aircraft, it enables the pilot to guide himself at a point where radio-range beacons (see Secs. 9.11 and 9.12) are not available, or to determine the position of the aircraft.

To facilitate the taking of accurate marine bearings, there have been established by the United States Lighthouse Service almost a hundred radio beacons on most of the important lighthouses and lightships on both coasts of the United States and on the Great Lakes. These beacons transmit in the band 285 to 315 kilocycles.

Radio beacons are transmitters that radiate equally well in all directions, and, as their position is accurately given in the publication "Commercial and Government Radio Stations of the United States," any bearing taken on these beacons may be considered as being accurate bear-

ings from a given point. By taking bearings from two such points, the exact location of the observer may be ascertained by cross triangulation.

Regular radio-beacon stations emit a characteristic signal which can be readily distinguished by any one without a knowledge of the International Telegraph Code. They are so located that bearings taken on them by vessels will in most cases be entirely over water. Radio-beacon stations operate continuously in thick or foggy weather, and at other regular intervals as set forth in the above-mentioned publication.

A system consisting of radio direction-finding stations is maintained by the United States Navy at the entrances to the principal harbors on both coasts. More than half of these will transmit as a radio beacon on 375 kilocycles (800 meters) upon request. These stations are also listed in the publication referred to before. Any ship fitted with a radio compass may, therefore, take a bearing on any of these stations.

It is also possible for a vessel fitted with a radio direction finder to take a bearing on any commercial or government shore station which bearing might be useful provided the exact geographical location of the transmitting aerial is known. This practice is not recommended unless it is impossible to take a bearing on a radio beacon.

The navigator aboard a ship fitted with a direction finder may take bearings on another ship, a possibility which is especially useful when proceeding to a ship in distress or to any ship with which it wishes to make contact.

16.2. Elements of Direction-finder Apparatus. *a. Description.*—The radio-direction-finder installation, a commercial model of which is shown in Fig. 16-1, consists of a loop, a bearing indicator, a receiver, and a signal-intensity indicator which may be of the aural (headphones) or visual (meter or lamp) type. A mechanical drawing of the assembled apparatus is shown in Fig. 16-2.

The loop is mounted on a pedestal above the deck or radio direction-finder housing and is arranged so as to permit complete and continuous

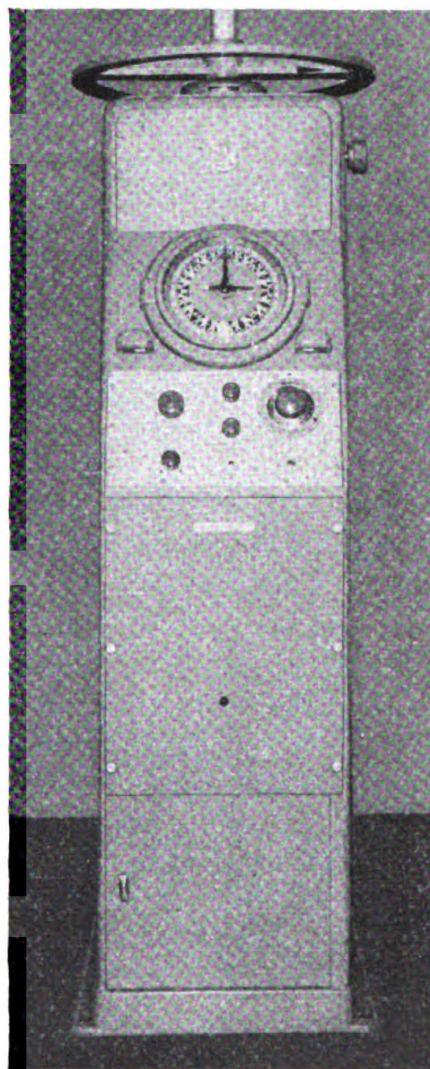


FIG. 16-1.—R.M.C.A. Model AR-8703-B radio direction finder. (Courtesy of R.M.C.A.)

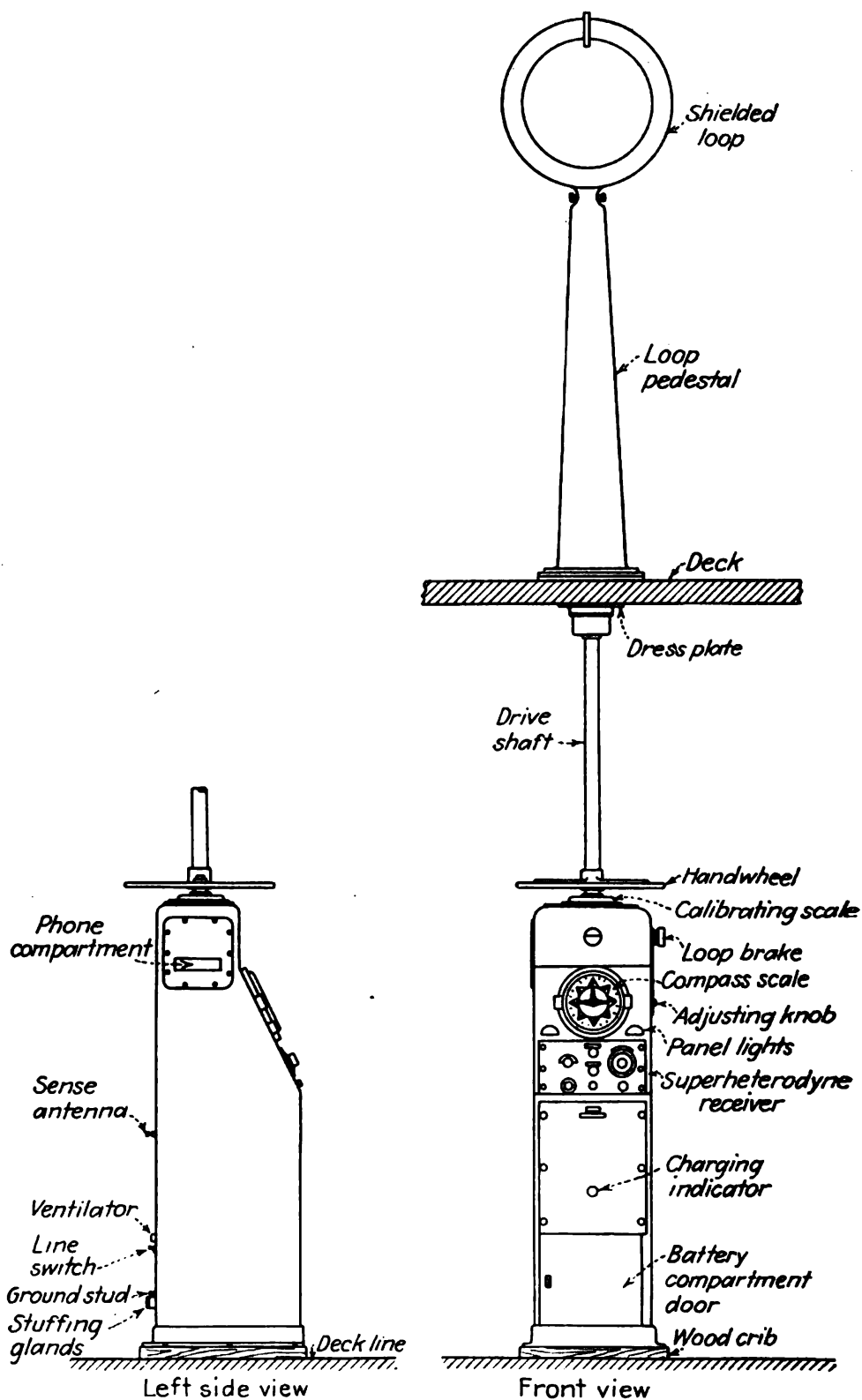


FIG. 16-2.—R.M.C.A. Model AR-8703-B radio direction finder mechanical arrangement.

orientation about its vertical axis by means of a handwheel and a set of reducing gears. The loop is generally wound with a special radio-frequency cable, the number of turns depending on the wave-length range to be covered and the size of the condenser used with the loop. A loop measuring approximately 2 ft. in diameter wound with about 10 turns of No. 20 B. and S. wire, or its equivalent in a stranded cable, will when used with a 0.001-mf. variable condenser tune to the 800-meter direction-finder wave.

b. The bearing indicator varies with the type of direction finder used. On direction finders designed for installation on large vessels engaged in deep-water navigation, the indicator consists of a dumb-compass card mounted so that readings may be taken in degrees from the ship's head, or the card may be adjusted so that the bearings may be taken relative to the meridian. This card is illuminated by a small light concealed in the base. Bearings may be read by means of *parallel lines* engraved on a piece of heavy plate glass or parallel wires held by two arms which revolve about the compass card as the loop is turned. On ships fitted with a gyrocompass the dumb-compass card may be replaced by a live gyro-repeater. In installations of this kind the bearings are true bearings and are read from a small scale engraved on the outer edge of the gyro-repeater.

On smaller types of direction finders a 360-degree scale is provided over which revolves a pointer attached permanently to the loop shaft.

The types of marine-radio direction finder, shown in Fig. 16-2, usually have two pointers (colored red and white) fixed so that they point in opposite directions and at right angles to the parallel lines. These pointers are useful when it is desired to utilize the unidirectional qualities of the direction finder, as will be seen when the practical operation of the direction finder is explained.

c. The receiver utilized with a radio direction finder must be designed to give maximum sensitivity and selectivity together with simplicity of operation. When push-pull radio-frequency amplification is used, it is provided to give electrical symmetry to the loop circuit and reduce antenna effect. On radio direction finders designed for use where great accuracy is not required, push-pull radio-frequency amplification is not provided. Also, on direction finders designed for installation in sea-planes, where antenna effect is not pronounced owing to the absence of surrounding metallic objects which are grounded, push-pull radio-frequency amplification is not necessary. The expense of construction on these receivers is, therefore, proportionately less.

d. The frequency range of marine-radio direction-finding equipment generally falls within the band extending from 250 to 540 kilocycles. This allows operation on the three principal direction-finder frequencies, namely, 300, 375, and 500 kilocycles. Radio beacons operate on 300 kilocycles; radio-compass operation is carried on between ships, and

between ship and shore, on 375 kilocycles; and 500 kilocycles is the distress frequency on which direction-finder operation might be necessary in locating a vessel in distress. Radio direction-finder receivers are usually calibrated for these three frequencies.

16.3. Grounds and Shielding.—It is the usual practice to mount direction-finder receivers in a metal case which acts as a shield and reduces antenna effect. In addition to this, any external leads from the loop or battery box (if it is a separate unit) are shielded, and all shields are grounded.

A grounded electrostatic shield is also advantageously placed between the primary and secondary of the output transformer of the receiver. This shielding is provided to reduce antenna pickup by the telephones and connecting cord which causes residual signal.

16.4. Signal Indication.—Signal intensity may be indicated by the visual methods or by the aural method. The latter is perhaps the most commonly used and requires ordinary radio headphones connected to the receiver to indicate maximum and minimum signal reception in the operation of the direction finder. The visual methods are less commonly employed but, nevertheless, are very practical for strong signals.

One visual system of indicating signal strength utilizes a special type of lamp containing an inert gas (usually neon gas). This lamp is connected directly in the loop circuit, and its operation may be described as follows.

If the loop is rotated to a position where maximum e.m.f. is induced in it, it will be seen from previous explanations that the current will be a maximum if the loop is parallel to the line of direction of travel taken by an oncoming wave; consequently, if the loop is at right angles to the direction of travel taken by the wave, a minimum of current will flow in the loop.

If the e.m.f. induced in the loop is large enough, it will ionize the gas medium in the tube which will result in a glow. Then as the loop is rotated to a point where the minimum signal is induced into it, the lamp will not glow. Thus it will be seen that the lamp will cease to glow between two readings on the compass card, the *mean* of which will be the actual bearing.

It must be borne in mind, however, that the width of the compass sector over which the lamp is dark will depend on the strength of the transmitted signal and also the distance from the transmitting station to the ship which is taking the bearing. It has been found that a reading accurate to 2 degrees can usually be obtained over a distance of 25 miles.

An advantage of this system over the aural system is that it is possible to rotate the loop to a point so that a signal transmitted from either a land beacon or a mobile radio beacon installed on another ship will cause the lamp to glow as soon as the vessel, on which the glow lamp is installed as a part of the direction finder, comes into a danger zone, thus making it possible by this means to have the lamp placed in a conspicuous position whereby the navigator may observe approaching danger by occasionally *glancing* at the lamp.

Another type of visual indicator is the meter type. The scheme here is to connect a sensitive rectifier-type voltmeter across the output of the receiver in place of, or in addition to, the ordinary headphones. This type of indicator should prove helpful when there are noises in the same room with the direction finder which makes listening difficult. This visual indicator will of course respond to interfering signals in the direction finder, but, under favorable conditions, coordination of the visual and aural methods of observation should improve accuracy.

16.5. Reducing Deviation.—On large vessels where the loop can be placed relatively free from surrounding objects, the means for eliminating antenna effect by means of a balancing circuit, as described in Sec. 7.13, are generally sufficient. On the other hand, on smaller vessels and on some large ones, lack of space makes it necessary to place the radio-direction-finder loop in the midst of metallic circuits such as stays, smokestacks, and iron railings. Under these conditions additional precautions and methods of eliminating deviation must be taken.

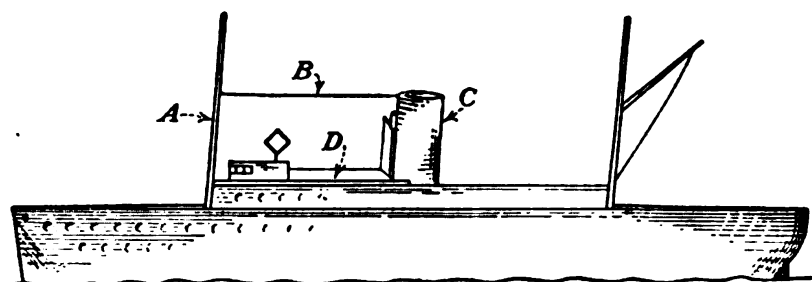


FIG. 16-3.—Use of compensating loop (A, B, C, D) to reduce deviation.

On small vessels where a clear open space cannot be found for the loop, serious deviation may result owing to spurious fields set up by surrounding metallic objects. If the deviation thus set up is more than 20 degrees, it is considered excessive and steps must be taken to reduce it to normal. This may be done by the use of *compensating loops* which are formed by connecting together the various metallic circuits so that they form closed loops as shown in Fig. 16-3. Side A of the loop is formed by the metal mast; side B, by a wire connecting the mast and smokestack; side C, by the smokestack; and side D, by the iron railing which is electrically connected to the mast and stack.

The electrical dimensions of the compensating loop are important. Care must be taken not to make the compensating loop resonant with the direction-finder circuit. If this happens, the deviation will be enormously increased. On the other hand, if the compensating loop is not large enough, an overcompensated condition will result which will spread the deviation over a wider arc than when the proper compensating loop is used. In addition to altering the electrical dimensions of the compensating loop by varying its mechanical size, the electrical characteristics of this loop may be varied by the insertion of lumped resistance

inductance, or capacity in series with it. For example, a resistance, coil, or condenser may be inserted in series with the wire *B* of Fig. 16-3. Typical effects before and after the installation of a compensating loop are shown by the two curves in Fig. 16-4.

If only normal deviation is encountered, this is compensated for by a mechanical compensator which automatically causes the indicator to lag or lead the plane of the direction-finder loop by the necessary amount. The mechanical idea of this compensator is shown in Fig. 16-5.

After the radio direction finder has been calibrated and placed in operation, care must be taken to see that no large masses of metal in the vicinity are shifted in position, as this would probably affect the calibration. No local radio antennas should be moved (watch broadcast-

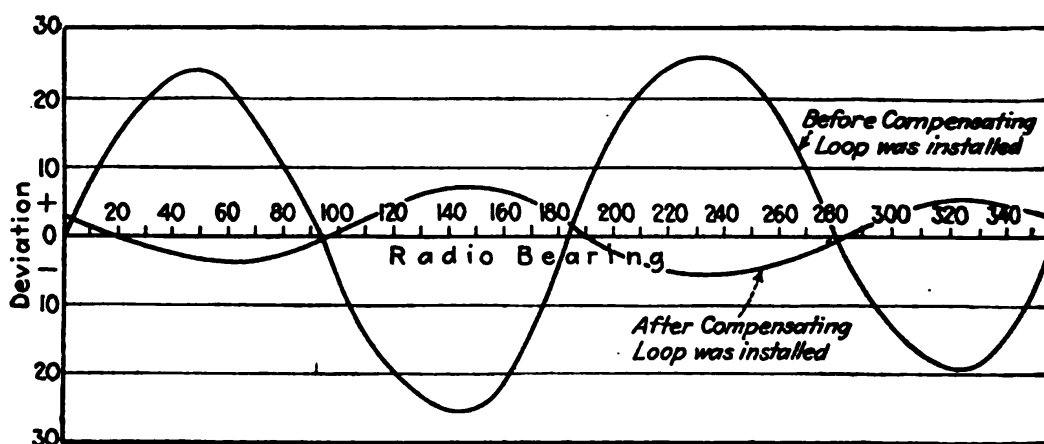


FIG. 16-4.—Error curve before and after installation of compensating loop.

receiver aerials too), and all antennas should be open-circuited (not grounded) while the radio direction finder is in use.

On shipboard installations, the average deviation, as shown in Fig. 16-4, is about as follows, starting at the bow and rotating clockwise.

Degrees (approximate)	Deviation
45.....	Maximum (positive)
90.....	Minimum
135.....	Maximum (negative)
180.....	Minimum
225.....	Maximum (positive)
270.....	Minimum
315.....	Maximum (negative)
360.....	Minimum

16.6. Commercial D/F Models.—The radio direction finder as used aboard ship is the result of many years of scientific development in the laboratory and practical use at sea. Today the radio direction finder is as essential a part of the navigational equipment of an ocean-going steamship or comparable Great Lakes vessel as are the sextant and pelorus.

With the radio direction finder, bearings can be taken regardless of weather, thus eliminating one of the greatest hazards of navigation. Commercial models of radio direction finders, such as are described in this section, are designed for installation on the navigation bridge or chart house and for operation by the navigator himself.

1. R.M.C.A. MODEL AR-8703-B. *a. General Description.*—The main compass scale (card) of this direction finder, which is shown in Fig. 16-1,

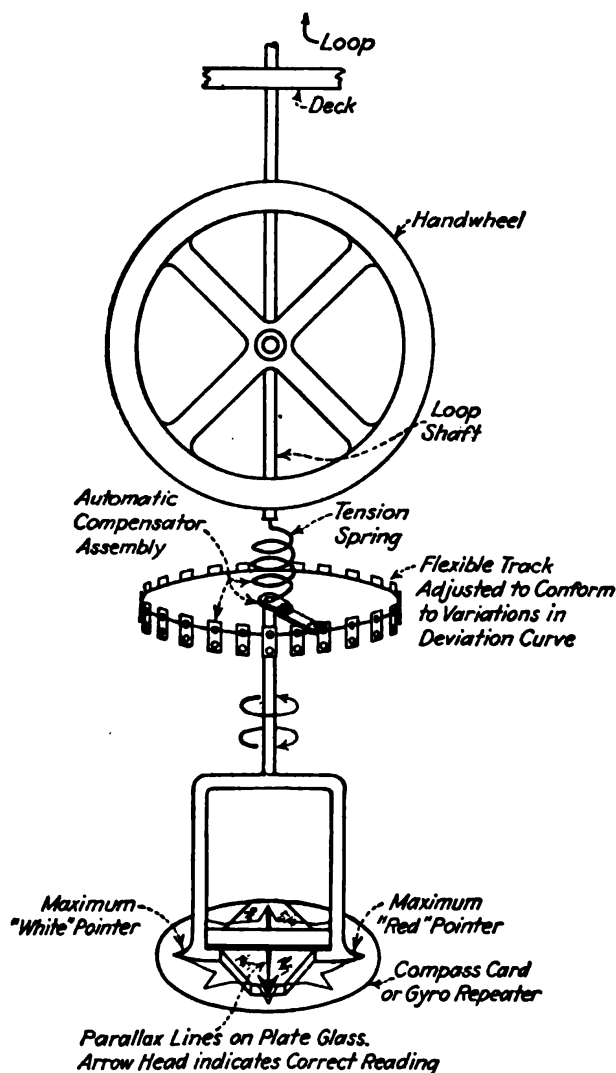


FIG. 16-5 —Mechanical arrangement of automatic compensator to loop shaft.

is designed so that it may be controlled with a gyro-repeater motor. This motor is mounted behind the scale. A small recessed adjusting knob at the right of the binnacle permits the compass scale to be adjusted to the ship's course in case the master gyrocompass has been shut down and then started up again. This same adjusting knob should be used to set the compass scale to the ship's lubber line or, if desired, to the ship's course in installations which do not use a gyro-repeater system.

It will be apparent that with gyro-repeater installations the radio bearings are true north.

A fixed outer scale is also mounted on the indicator housing, just outside the movable compass scale. This fixed scale may be used to advantage when taking radio bearings with respect to the ship's bow such as when heading toward a radio beacon or to another vessel. Caution must be exercised at all times when taking bearings while approaching lightships or lighthouses to insure setting the course to pass safely clear.

A calibrating scale (for principal use by the calibrator), mounted on a drum beneath the handwheel, is provided to show the position of the loop with respect to the ship's lubber line. This scale gives *uncorrected radio bearings*, and may, therefore, be used to check the amount of correction for which the compensator is adjusted by comparing the readings on the *calibrating scale* with those given by the *fixed outer scale*.

A small rheostat (compass-card light control) is mounted on the receiver panel, with convenient control knob, to enable the user to adjust the amount of indirect illumination that is provided for the main compass scale. Telephone receivers when not in use should be stowed in the upper left binnacle pocket that is provided.

In order to lock the loop to prevent unnecessary wear and tear on the entire mechanism when the direction finder is not in use, there is provided a locking knob in the upper right-hand section of the binnacle. Always lock the loop after using so that strong winds will not cause rotation.

A highly developed *superheterodyne* eight-tube radio receiver is mounted near the top section of the binnacle. This receiver, a schematic diagram of which is shown in Fig. 16-6, is capable of amplifying very weak signals so that the atmospheric noise (static) is the principal limiting factor in determining distance range rather than any lack of receiver sensitivity. The receiver also possesses high selectivity, which is essential in order to eliminate signals from interfering stations. A full-vision *tuning* control, calibrated directly in kilocycles, is used to the receiver panel. Marine radio beacons operate in the band from 285 to 315 kilocycles, and this beacon band is marked with a *red* sector on the dial. The full tuning range is 270 to 520 kilocycles to enable the direction finder to be used to take bearings on other ships or stations that transmit within this band.

The master switch which controls the direction finder is mounted in the center section of the panel. When this switch is turned to the ON position, it energizes a signal light in the radio room to inform the radio operator that the direction finder is to be used. The radio operator will then *disconnect* his main antenna (which may cause errors unless disconnected from the radio equipment) and will also *close* an interlock circuit to a relay in the direction finder. As soon as he does this, the *panel light* on the direction finder and the compass scale lights will be

illuminated, the tubes will warm up in about 15 sec., and the direction finder is ready for use. Placing the master switch in the OFF position will extinguish the radio-room light and will automatically place the direction-finder storage battery on charge. A small glass lens on the binnacle access panel will glow to indicate that the storage battery is being charged.

The balance control (RCA magnetic type) is mounted in the upper left section of the receiver panel. It performs two functions. When taking bearings a careful adjustment of the balancer will "sharpen" the point of minimum or zero signal strength. If the "sense" of direction of the bearing is not known, the balancer pointer should be turned to the SENSE position and held there against the spring tension. The loop is then turned a few degrees to the right or left of the bearing position. If the signal increases *more* when the compass pointer moves toward a *lower* reading than it does when the pointer moves the same amount toward *higher* readings, the sense of the bearing is correct. However, if the signal increase is greater when the pointer moves toward higher readings, then the bearing is 180 degrees in error and the loop should be turned 180 degrees and a new bearing taken. Familiarity in determining "sense" may be acquired by taking practice bearings whose sense is already known so that in emergencies or when a bearing is taken on a ship in distress there will be no danger of 180-degree ambiguity.

Volume control for adjusting the strength of the signal in the headphones is provided by the control in the lower left section of the panel. Use *low* volume to *tune* the receiver accurately to the desired beacon station. Use *high* volume when taking the bearing (loop or minimum signal) as this will sharpen the bearing. With severe static, the volume control must of course be adjusted so that the headphone signal is not uncomfortably loud.

A C-W switch in the lower right section of the panel will enable continuous waves or modulated waves to be given a characteristic note. Turning this switch on will be found to assist in taking bearings under unfavorable conditions of static or interference.

b. Operating Procedure.—1. Turn master switch ON. Unlock loop. Plug in phones. Panel and compass card will be illuminated as soon as radio operator closes his interlock switch. Tubes will warm up in 15 sec.

2. Tune in signal accurately with Tuning dial, using low or medium Volume, until signal in headphones is a maximum. Identify the signal by its characteristic code as shown on United States Coast Guard radio-beacon charts.

3. Take radio bearing by turning loop until signal falls to zero or minimum. Turn BALANCE knob a little to right or left of zero on scale to sharpen the minimum. Correct bearing point is the NO-SIGNAL position of loop and may be checked by noting that signal increases when either

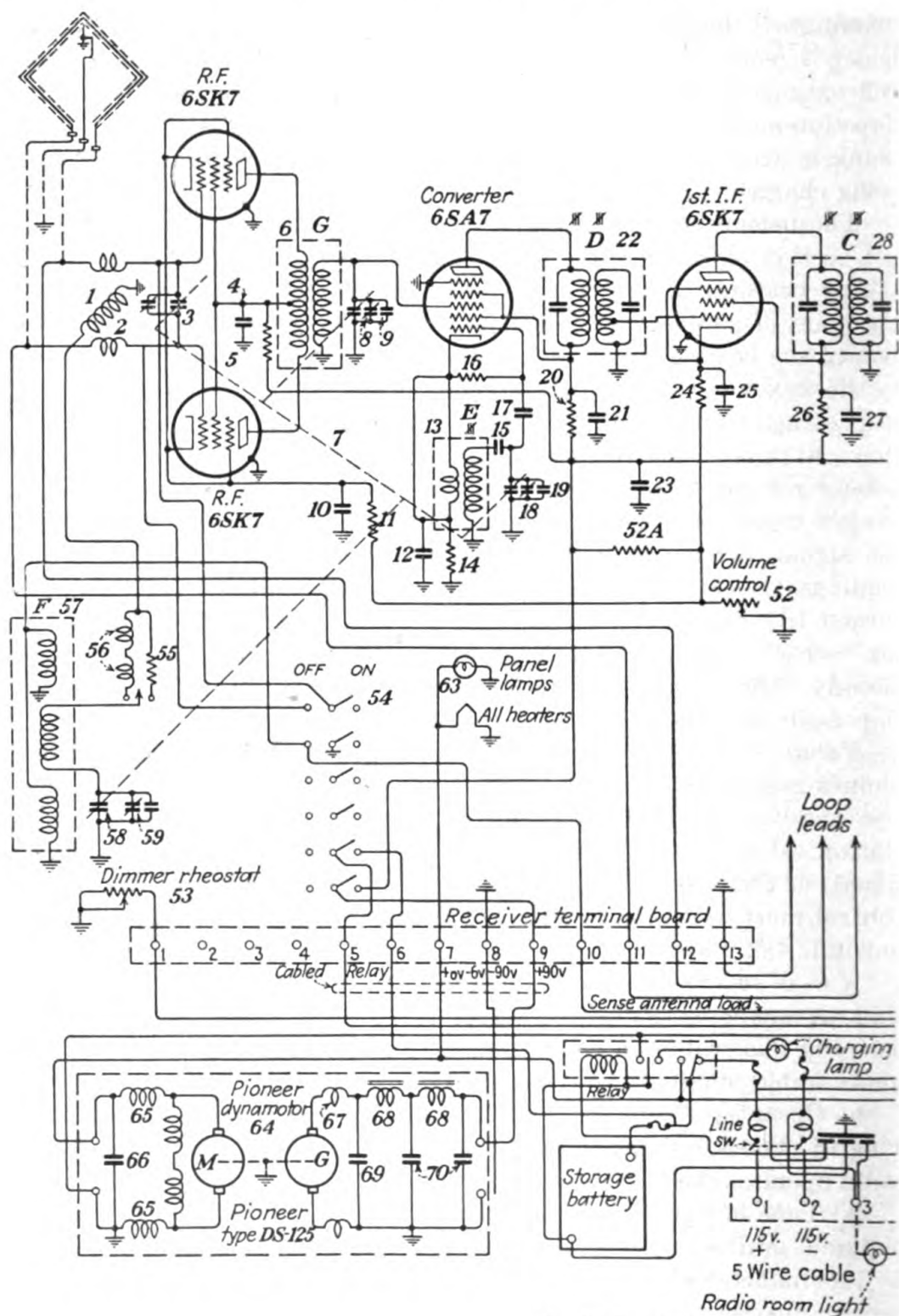
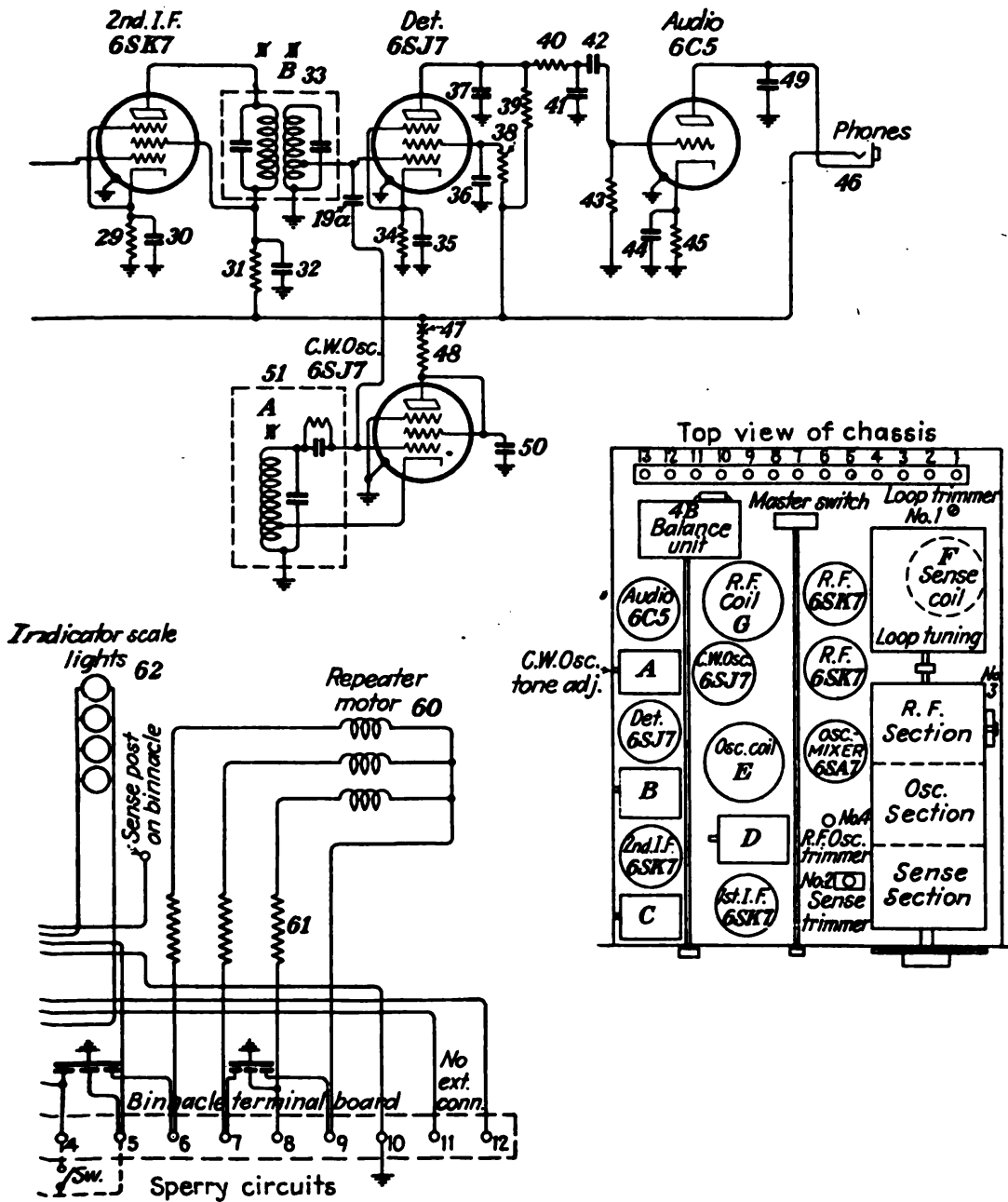


FIG. 16-6.—RMCA Model AR 8703B



Radio Direction Finder circuit.

the loop or balance are moved slightly. Use a fairly high *Volume* setting to secure a clearly defined bearing point.

4. If "sense" of incoming signal is known, always rotate loop so that pointer over compass card is in the correct quadrant when taking bearings. If sense is not known, take a bearing and then hold *BALANCE* pointer to the *SENSE* position on scale. Now turn loop so that compass pointer moves toward *lower* readings on card and observe if signal *increases* more than when pointer is moved the same number of degrees toward higher readings on card. If the increase in signal is greater toward lower readings sense is correct, and the red stub pointer will point nearer the bearing position than the *white* stub pointer. If opposite conditions are observed, the loop should be turned 180 degrees and a new bearing taken and sense checked once more.

5. Most United States radio-beacons operate in groups of three on the same frequency, so that after one station is tuned in, bearings may quickly be taken on all three stations and then laid off on the chart for a "fix."

c. Installation Notes.—In accordance with *Radiomarine* standard procedure, when the direction finder is calibrated the main pointer over the compass card must always be adjusted so that it is on zero after the loop has been locked for a true "dead-ahead" radio bearing. The pointer may be adjusted to within a few degrees of zero by reaching in the back of the binnacle, unmeshing the gear on the pointer shaft, and then meshing it again when the pointer is at or near zero. To secure an exact adjustment of the pointer, loosen the two set screws located on the spindle near the rear bearing and then turn the pointer by means of the knurled adjustment knob. The two set screws should then be firmly tightened with the pointer adjustment at zero.

Repeater motors, when used, need to be carefully lined up so that the worm gear meshes nicely with its pinion. If this adjustment is too tight, the repeater motor may be loaded too heavily, or if too loose there will be backlash in the gearing. An adjusting screw and lock nut is provided at the top of the Sperry motor-assembly bracket to permit the tension on the worm gear to be adjusted.

The indicator lights at the rear of the main compass scale may be replaced by carefully removing the glass cover over the scale, and then removing the two screws that hold each lamp socket. Lamps should *not* be replaced with the current turned on. When replacing lamps, care should be taken to dress the leads back with care so that grounds or shorts do not occur and to prevent the lamp leads from fouling the rotating compass scale. The pilot lights for the receiver panel are replaced by removing the small light shields which are located directly above the receiver panel. Access to the main incoming terminal board in the lower section of the binnacle is obtained by opening the bottom door and removing the sliding lead-lined battery tray. This tray should be tilted slightly to enable the barrier board at the rear of the tray to clear the opening.

Access to the dynamotor (which is used to supply plate potential), relay, and charging-lamp compartment is obtained by removing the vertical panel on the front of the binnacle. When replacing this panel, it is important to draw up the screws tightly to insure good electrical contact and shielding.

The AR-8703-B uses a highly developed eight-tube superheterodyne receiver. Each receiver is carefully aligned and adjusted in the laboratory with precision instruments, and field personnel are cautioned not to disturb any adjustments unless a definite procedure is followed, together with a full understanding of the various cir-

uits involved. Under normal circumstances, the only receiver adjustments that should be made by field personnel are line-up of the loop circuit by means of the loop trimmer condenser (No. 1) and adjustment of the sense trimmer circuit (No. 2). The main loop-tuning condenser, which is ganged with the other three-section condenser should not be disturbed, as all four variable condensers should be *fully meshed* when the main tuning scale is set at its last major division (260 kilocycles).

All tubes in the receiver use the same octal base socket, and all tubes are of the single-ended type, eliminating grid caps. For this reason, it is important to insure that the correct tubes are in the correct sockets as shown on the schematic diagram and as stamped on the receiver chassis. The tube complement is as follows:

Two 6SK7 balanced radio-frequency amplifiers.

One 6SA7 converter (mixed oscillator).

One 6SK7 first intermediate amplifier.

One 6SK7 second intermediate amplifier.

One 6SJ7 second detector.

One 6SJ7 C-W oscillator.

One 6C5 audio amplifier.

The master switch, controlled from the receiver panel, is a six-pole double-throw unit. Two poles are not used. In the *OFF* position, the switch short-circuits the loop, grounds the sense antenna, disconnects +90 volts, and deenergizes the relay which stops the dynamotor and places the *A* battery on charge through the charging lamps. When the master switch is placed in the *ON* position, it removes the short from the loop and the ground from the sense antenna, closes the 90-volt plus *B* circuit, and energizes the radio-room red light. When the radio operator closes his interlock switch, this energizes the binnacle relay, applying 6 volts to the receiver and the panel lights and starts the dynamotor.

The main tuning control which is connected to the four-ganged condenser is calibrated in kilocycles. The specified tuning range is 270 to 520 kilocycles, with a small overlap at each end. Attention is directed to the red sector on the tuning dial for the 285- to 315-kilocycle beacon band. Note that the tuning dial provides markings every 2 kilocycles from 270 to 320 kilocycles, and every 10 kilocycles from 320 to 520 kilocycles.

The balance is the standard *Radiomarine* magnetic balance with sense position and is controlled from the receiver panel.

The *C-W* switch on the receiver panel controls the plate circuit of the 6SJ7 *C-W* oscillator tube, so that incoming signals may be heterodyned. The output of the *C-W* oscillator tube is loosely coupled to the grid of the second detector tube. The *C-W* oscillator is adjusted to operate at 174 kilocycles so as to provide a 1,000-cycle beat note with 175 kilocycle intermediate frequency. The adjustment for the *C-W* oscillator is a small knurled nut on the transformer can marked *A*. If it is found necessary to adjust this unit, a modulated signal should first be *accurately* tuned in with the *C-W* switch in the *OFF* position, and then leaving the main tuning dial unchanged, adjust the oscillator can *A* for a suitable beat note. Owing to the high selectivity of the receiver, this adjustment must be made with care, and it is important to insure that the incoming signal is accurately tuned.

Volume control from the front panel is obtained by means of a 10,000-ohm unit, which is connected in the cathode circuits of all radio-frequency and intermediate-frequency tubes. A bleeder resistor, item 52A on the diagram, in the volume-control circuit permits a wide range of volume control to be obtained.

The telephone receivers are connected in series with the plate circuit of the 6C5 audio-amplifier tube. A special Carter No. 7 flat telephone plug is used, and care should be taken when connecting the phones to this plug to insure that the red lead on the phone cord connects to the *left* terminal on the plug. This is to prevent demag-

netization of the phones. The +90-volt circuit in the receiver connects to the *tip* of the phone jack so that the exposed *sleeve* portion of the jack does not have voltage on it when the phone plug is withdrawn.

Care should be taken to maintain the correct polarity of the 110-volt charging circuit so that terminal 1 is positive. A ground stud at the rear of the binnacle near the stuffing glands is provided, and it is *very important* to run a good low-resistance ground connection between this stud and the ship ground. Do not depend upon the binnacle ground obtained through the binnacle-base mounting studs. Failure to observe this precaution may result in noise in the receiver from the incoming power circuits. Attention is directed to the filter system built into the binnacle. The 110-volt charging circuit passes through a pair of radio-frequency chokes, and on the "load" side of these chokes, 0.1-mf. filter condensers are connected to suppress induction. Additional 0.1-mf. filter condensers are mounted in the binnacle to provide radio-frequency by-passing for the seven additional incoming leads. These additional condensers may either be connected or disconnected as determined by trial if induction is present.

The storage battery to be used with the AR-8703-B should be an *Exide* HDL-11 or its equivalent. This battery has sufficient capacity to operate the direction finder for a continuous period of approximately 16 hr. The total drain from the battery is 5.6 amp. The dynamotor requires about 2 amp., receiver tubes 2.2 amp.; and the radio-room red light, indicator and panel lights, and relay coil about 1.4 amp. *Mazda* No. 40 brown bead compass and panel lights should always be used to insure minimum current drain.

A 25-ohm rheostat, which is connected in series with the compass-indicator light, is mounted on the receiver panel. The purpose of this rheostat is to enable the navigator to adjust the brilliance of the main compass scale to the desired degree.

Adjustment of Sense Circuit.—Take a bearing on a signal of known frequency on 500 kilocycles, or as near to this frequency as possible. Place a temporary short around the 100-ohm resistor on the balancer unit. Hold balancer in *SENSE* position, and adjust the sense trimmer marked No. 2 on the chassis for maximum signal. Adjust the volume control at the same time so that resonance, as indicated by adjusting the trimmer condenser, is clearly defined. Then lock this condenser and remove the short from the 100-ohm resistor. Next, rotate the loop toward lower readings from the bearing point and check that the signal increases more than it does when the loop is rotated the same number of degrees toward higher readings on the scale. If this effect is not obtained, reverse the loop leads to terminals 11 and 12 on the receiver chassis and check again for correct sense indication. Sense action should then be checked on a signal around 300 kilocycles to insure that a proper indication of sense is obtained. Do not adjust sense trimmer condenser on signals in the beacon band, as resonance will not be obtained.

The loop trimmer condenser marked No. 1 on the chassis should always be adjusted for maximum signal when the receiver is accurately tuned to a beacon frequency. First, tune the signal with the main tuning control for maximum output. Then regulate the volume control so that the signal is fairly weak and adjust No. 1 loop trimmer condenser for maximum response.

The following adjustments should not be attempted unless it is definitely known that the entire chassis requires realignment. Tune in a signal of *known frequency* in the beacon band. Observe if the main tuning-dial calibration is accurate. If, for example, the known signal is 314 kilocycles, set the main tuning dial at 314 kilocycles and leave it there whether or not the signal is heard. Then adjust the 300-kilocycle oscillator adjustment on can marked *E* until the signal is heard and until it is a maximum. Loop trimmer condenser 1 should always be adjusted for maximum without disturbing the main tuning dial and using a low enough setting on the volume control so that resonance is clearly observed. Next, tune the receiver to a known 500-kilo-

cycle signal; *leave the main tuning dial at 500 kilocycles*, and adjust the 500-kilocycle oscillator trimmer 4 and 500-kilocycle radio-frequency trimmer 3 until the signal is heard at a maximum. It is emphasized that all such adjustments should be made by setting the main tuning dial exactly at the calibrated point for the known frequency, as otherwise the calibration on the tuning dial may not hold throughout the range.

The intermediate frequency of the receiver is 175 kilocycles. No attempt should be made to align all the intermediate-frequency transformers (transformers *B*, *C*, and *D*) on incoming signals. The intermediate-frequency transformers are of special design, and will not drift out of adjustment in service. If, however, any *one* of these transformers requires replacement in the field, it may be aligned by tuning in a signal and then adjusting the two iron cores with the adjusting screws on the can, using a low volume-control setting during this work. Since the intermediate-frequency transformer adjustments are readily accessible only from the sides of the cans, it will be apparent that such adjustments should properly be made with the receiver out of the chassis and with an accurate 175-kilocycle modulated oscillator.

The 110-volt battery-charging circuit is disconnected when the small toggle switch at the rear of the binnacle is thrown to the *OFF* position. The 110-volt charging circuit is fused by 3-amp. glass fuses. The positive side of the 6-volt storage battery is fused by means of a 20-amp. glass fuse.

For ordinary use of the direction finder for approximately 1 hr. per day, with 110-volt direct-current supply, the charging lamps should consist of two 25-watt 120-volt lamps. These are connected in parallel in the binnacle. If the direction finder is used for longer daily periods, a pair of 40 or 50-watt lamps may be used. In the case of 240-volt ship supply, for 1 hr. daily service, two 50-watt lamps are recommended (see Sec. 18.14*d*).

Collector rings and brushes are made of solid silver and must not be cleaned with abrasives. Use carbon tetrachloride on a clean cloth.

Light grease should be used on compensator gears and light oil on shaft bearings, taking care not to use excessive amounts.

The main-line toggle switch behind the binnacle must be turned *OFF*, or the 110-volt circuit disconnected in the radio room, when the ship lays up or is in dry dock. Otherwise, the *A* battery will discharge back through the power line.

d. Calibration.—Calibration of the model AR-8703-B radio direction finder should be carried out using standard *Radiomarine* procedure. A true “dead-ahead” radio bearing should be taken and the loop firmly locked in position. Access to the calibrating scale, beneath the handwheel, should be obtained by removing the front half of the cover over this scale. The drum on which the scale is mounted may then be loosened from the drive shaft and reset so that the pointer reads zero. Then tighten up set screws and replace the cover. The ship should then be swung in the usual manner and simultaneous radio and pelorus bearings taken at least at every stud point throughout the azimuth so that an accurate calibration curve may be drawn. The loop pointer over the main compass scale should then be adjusted to zero, as previously described, and the compensator adjusted to correct for the observed errors. Care should be taken not to strain the band when adjusting it on the compensator. If a correction in excess of 25 degrees is required, which results in extending the band toward its limits, it is recommended that a special long band be installed. After the compensator has been adjusted, the accuracy of the compensator setting may be readily checked by comparing readings of the pointer over the fixed outer scale against the readings on the calibrating scale. A copy of the calibration record should be entered in the instruction book supplied or on a sheet provided for this purpose.

2. MACKAY TYPE 105-A RADIO DIRECTION FINDER. *a. General Description.*—This description covers the 105-A radio direction finder which is suitable for marine- or coast-station use and designed for

accuracy, sensitivity, and selectivity, together with simplicity of operation, installation, and servicing. The assemblies are constructed in a rugged, substantial manner with the use of non-magnetic materials wherever possible.

This radio direction finder is a binnacle-type unit designed for installation in the chart room or pilot house. The 27-in. diameter shielded loop is mounted on a large pedestal, the lower end of which passes through the deck to connect with the indicator and receiver cabinet assembly. The height of the pedestal is such that the lowest part of the loop winding is 6 in. above the hand rails to be found on most vessels. The loop winding is completely enclosed in a watertight housing made up of 3-in. outside diameter copper tubing bent to form a circle of 27 in. outside diameter. A Bakelite insulated joint is used at the top and a bronze casting with ball and sleeve bearings at the bottom. All fittings are securely brazed to the tubing to provide strength and rigidity. The complete assembly is designed to withstand a 200 mile per hour wind without damage.

The center of gravity of the complete direction-finder loop assembly has been placed at a low point so that in case of excessive vibration of the vessel the assembly will not tend to oscillate like a pendulum.

The winding consists of 18 turns of No 14 stranded rubber-covered wire supported on a system of Vulcoid spreaders to obtain minimum distributed capacity and a symmetrical winding. The lead wires are brought down the drive shaft on circular insulators and are ample spaced for low capacity. The center tap is also brought down to the receiver so that it may be disconnected for a leakage check. The complete shielding of the winding and leads eliminates any antenna effect of the loop and greatly reduces induction noises from electrical machinery in the vicinity of the installation.

The loop is rotated by means of the hand wheel which is mounted upon the sloping top of the binnacle. A friction brake is provided above the indicator housing for locking the loop in place when desired.

The indicator is of the mechanically compensated, fully automatic type in which the pointer showing the loop bearing leads or lags behind the actual loop position to compensate for radio errors noted at installation. It makes use of a stationary cam and a movable roller with associated linkage to actuate the pointer. A maximum correction of plus and minus 22 degrees can be obtained on the cam.

The indicator face carries a large full-vision dial showing the figure of a ship at its center, to aid the navigator in visualizing the bearings obtained with the equipment. A movable outer scale or Ritchie Ring, divided into 360 degrees, is provided for obtaining true bearings. This movable scale is designed to be operated by a Sperry repeater motor and thus maintain the true course reading on that scale at all times. "Off-

bow" bearings may be taken from the inner stationary scale. The long end of the pointer indicates the bearings on the scale, whereas the short end of the pointer is used in conjunction with the SENSE button on the receiver to remove the 180-degree ambiguity from the direction-pointer readings.

A glass cover protects the dial and pointer from damage. This assembly of the cam, pointer, and scales is mounted inside the hand wheel on the sloping top of the binnacles. This places the hand wheel and indi-



FIG. 16-7.—Mackay type 105-A radio direction finder in operation. (*Courtesy of Mackay Radio and Telegraph Co.*)

cator in a very convenient position, about chest high and at an angle of 45 degrees, as shown in Fig. 16-7.

The rear of the indicator housing encloses the loop collector rings and brushes also the gearing which connects the loop shaft to the hand wheel and indicator assembly. The collector rings and brushes are of Monel metal to prevent corrosion or noisy operation. A Bakelite terminal board is provided for securing the antenna and loop leads which connect to the receiver below. Grease cups have been provided on the loop and indicator bearings, the design being arranged to confine the lubricant to the desired surfaces.

Condensation within the loop and loop pedestal will drain down between the loop shaft and its housing and run out through two small holes at the top of the indicator housing. A heater lamp is provided within the binnacle to keep the interior dry.

A loud-speaker is mounted inside the top of the binnacle and is provided with a hinged cover which serves as a reflector to direct the sound toward the operator. A compartment with hinged cover is also provided at the top of the binnacle to house the headphones when not in use.

The outline drawing in Fig. 16-8 gives a clear view of the complete direction-finder installation.

The receiver, which is a single-control tuned-radio-frequency type, is set into the face of the binnacle immediately below the hand wheel and indicator assembly and is at an angle to provide good visibility. When not in use, it is enclosed by a hinged door which may be locked. The receiver employs eight 6.3-volt heater tubes of the latest types. The tuning range is from 255 to 550 kilocycles. The dial numbers increase with frequency and the points 300, 375, and 500 kilocycles are calibrated and engraved on the scale.

The other controls on the panel are the intensity control, antenna-balance control, sense button, *ICW-CW* switch, *OFF-ON* switch, and phone jack. The loop-capacity adjusting condenser is located under the receiver chassis as it is set only at installation and then locked in place.

The schematic diagram of the receiver is shown in Fig. 16-9. The first radio-frequency stage consists of two 6D6 pentode tubes connected in push pull and fed directly from the tuned balanced loop. The succeeding stages are tuned with twice the inductance and half the capacity of the loop circuit and also employ two 6D6 tubes. The 76 triode detector is fed from an untuned transformer peaked at 255 kilocycles, thereby compensating for the falling gain characteristic of the tuned stages.

The audio amplifier consists of two transformer-coupled stages employing type 37 tubes with an output transformer to match a pair of 20,000-ohm-impedance phones.

The beat-frequency oscillator is a 76 triode tube feeding the detector circuit through a small capacity. The tuning condenser of the oscillator is ganged with the radio-frequency amplifier tuning condensers, all of which carry trimmers for adjusting the minimum circuit capacity. The beat-note frequency is not affected by signal strength.

The loop tuning condenser is connected to the above condensers by means of an insulated flexible coupling.

Careful shielding of individual units in the receiver in addition to the complete shielding of the receiver cabinet makes the installation free from stray signal pickup and removes any couplings which may affect the accuracy of the bearings. The vacuum-tube circuits are properly by-passed to prevent interaction between the amplifier stages.

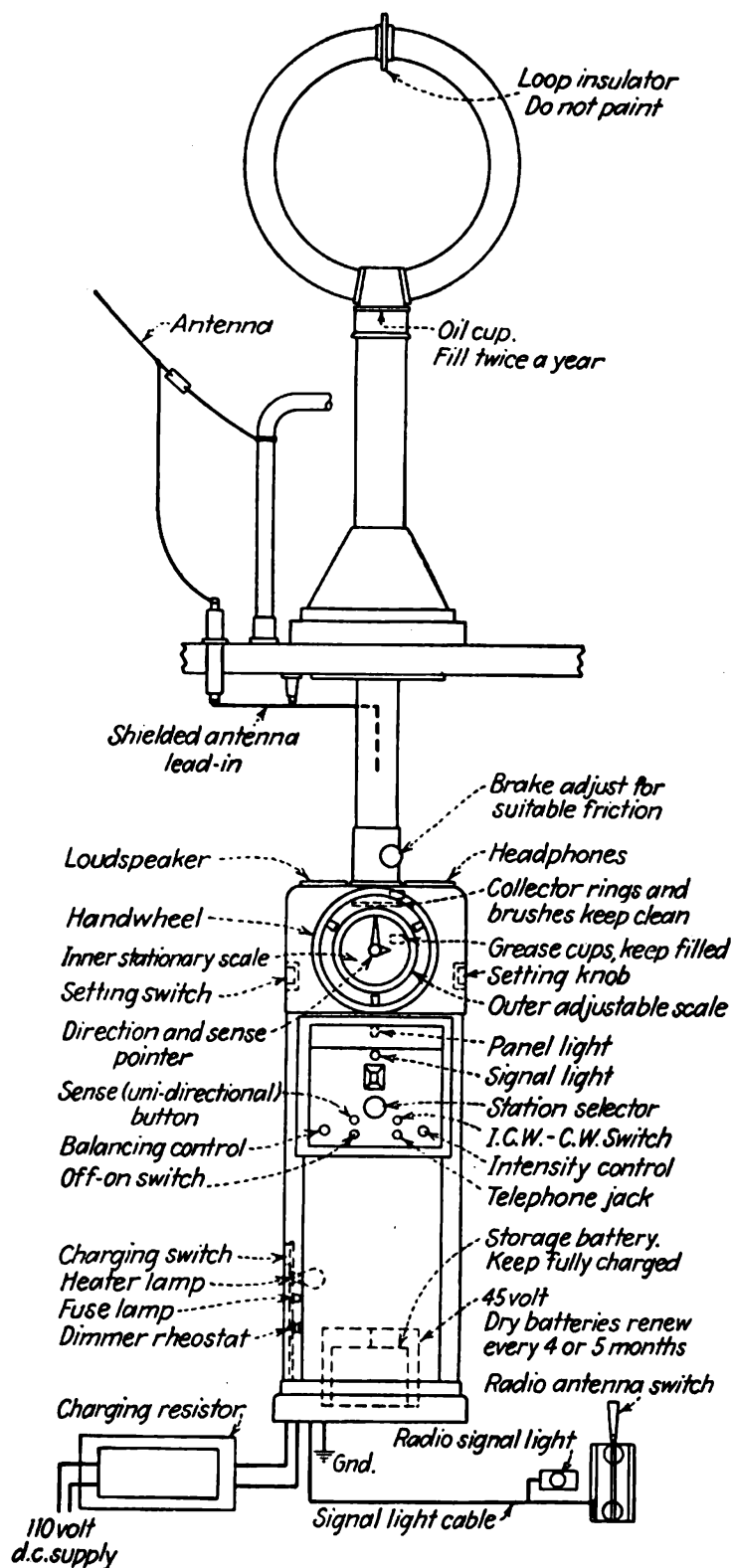
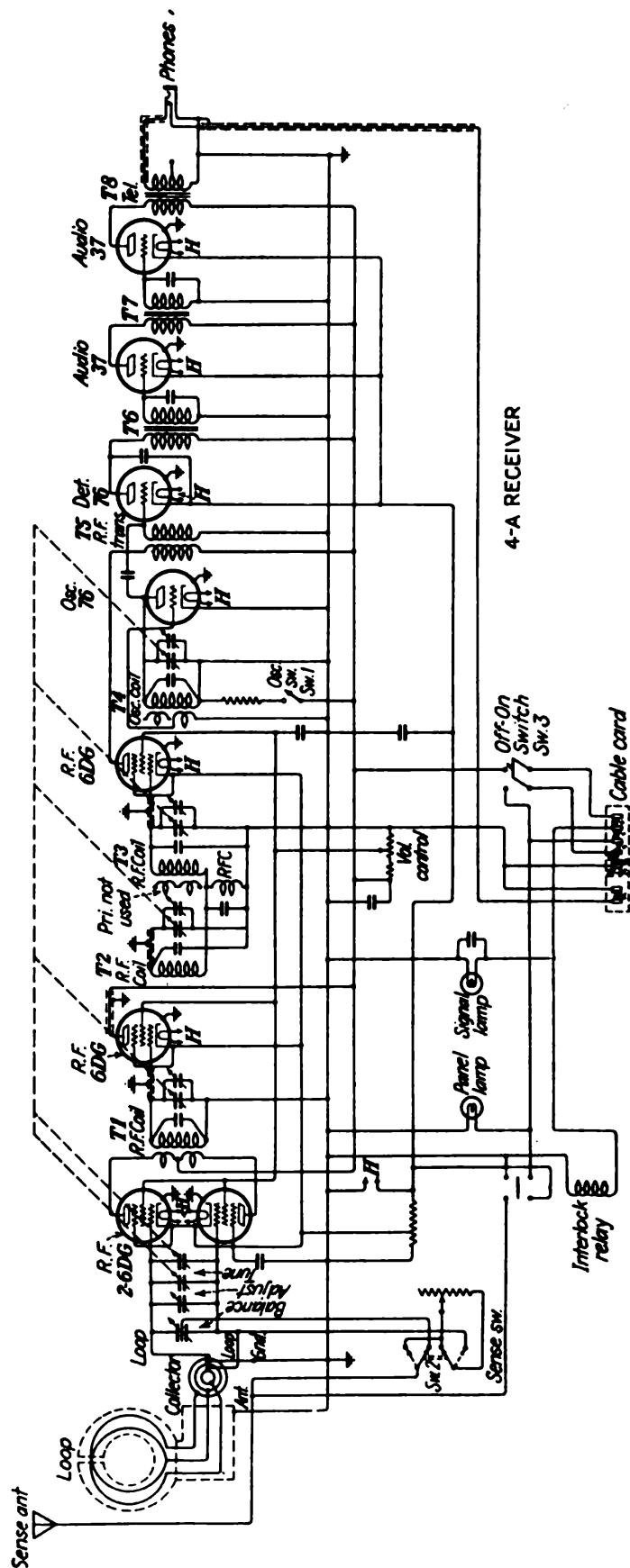


FIG. 16-8.—Mackay type 105-A radio direction finder mechanical arrangement.



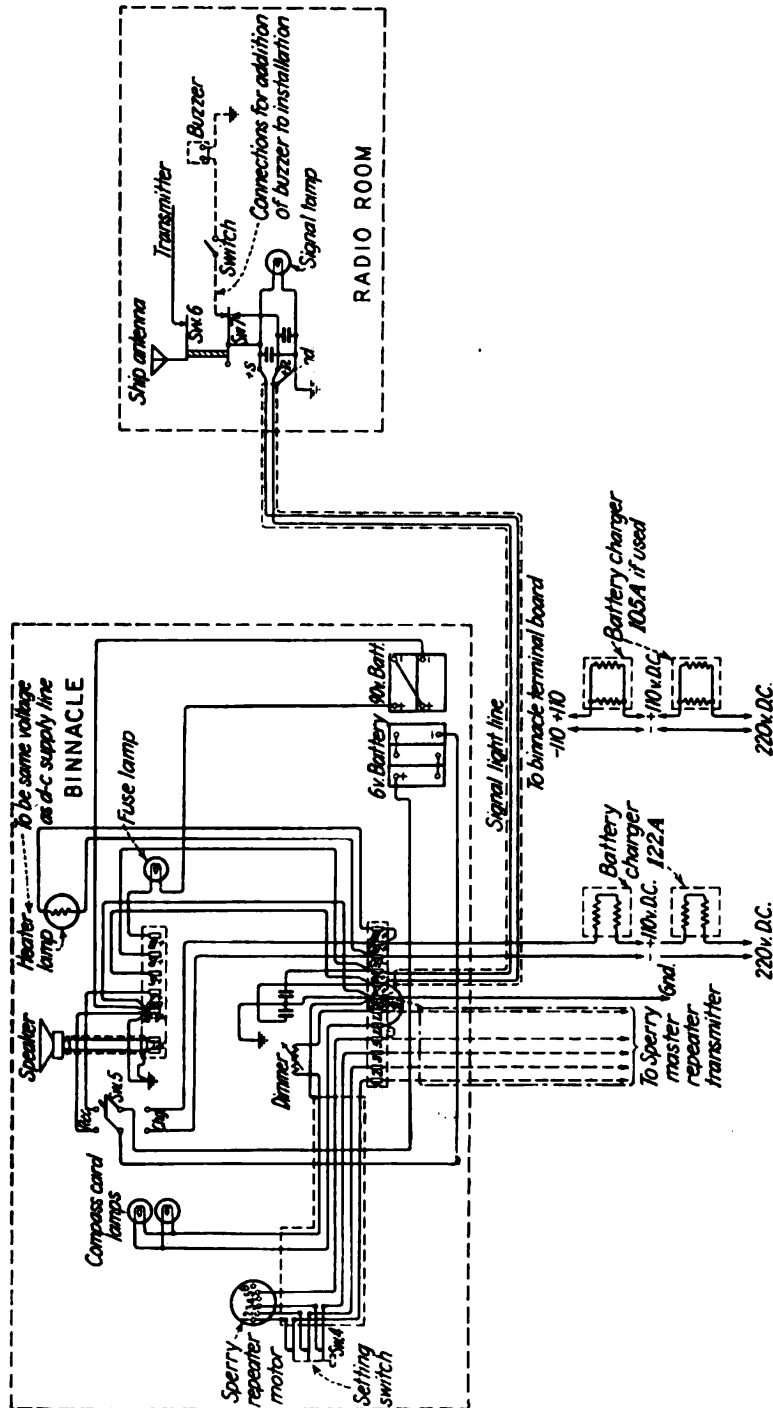


FIG. 16-9.—Mackay Type 105-A Radio Direction Finder circuit.

The screen-grid potentiometer control used in this receiver makes it possible to take bearings on very strong signals without overloading the receiver. The operation of this control has no effect on the receiver selectivity, frequency of the beat note, or the adjustment of the balance condenser. The width of the minimum may be set by this control to give a sharp null point, free from residual signal. The null point is not shifted by changes in the tuning control or balance condenser.

The *B* battery current drain of the receiver is 10 to 15 ma. at 90 volts, the higher value being for the maximum setting of the volume control. The *A* battery current drain of the complete installation is 3.15 amp. at 6.3 volts made up as follows:

8 vacuum tubes.....	2.40 amp.
60-ohm bias resistor.....	0.11 amp.
33-ohm relay.....	0.19 amp.
3 signal lamps.....	0.45 amp.
Total.....	3.15 amp.

This drain is for a normal installation with a Sperry repeater motor and indicator lamps fed from the Sperry supply. If a repeater motor is not used and the indicator lamps are 6- to 8-volt type, fed from the *A* battery, the total load on the battery will be increased to 3.45 amp.

No *C* battery is required as the bias voltages are obtained from the heater circuit by means of a tapped resistor which gives 1.5 volts bias for the radio-frequency tubes and 6 volts for the detector and audio tubes.

A relay is provided in the receiver which grounds the balance antenna and opens the heater circuit in its non-operated position. The green signal light on the receiver panel is lit whenever the relay is operated. A panel lamp is also provided on the receiver for illuminating the receiver panel.

The batteries for operation of the receiver and signal system are mounted on a tray in the bottom of the binnacle and consist of a 6-volt storage battery and two 45-volt dry *B* batteries. A wiring panel is provided and mounted on the left-hand inside wall of the binnacle to which all cables are run. This panel carries the charge-receive switch, terminal block for the receiver cable, heater lamp, *B* battery fuse lamp, indicator-lamp dimmer rheostat, by-pass condensers for signal line, and terminal block for all external wiring connections.

The handle of the charge-receive switch is accessible from the outside of the binnacle. Power for charging the *A* battery is obtained from the ship's mains and is regulated by an externally mounted series resistor. The charging rate is 3.5 amp. The fuse lamp is connected in series with the 90-volt supply to prevent damage to the receiver or batteries in case of a short circuit. The by-pass condensers are connected across the signal

light line to prevent any interference getting into the receiver from this source.

The antenna switch installed in the radio room is connected in series with the main transmitting antenna and to the direction-finder signal circuit so that when the antenna is opened the relay in the direction finder receiver is operated. The red signal light on the antenna switch remains lit all the time that the receiver is in use. The receiver cannot be used unless the antenna switch is thrown to the OPEN position.

The 5-A indicator has been designed to make use of a Sperry No. 80995 repeater motor to drive the bearings scale. Two Sperry No. 96666 70-volt 8-watt lamps are used for illumination of the indicator. A Sperry No. 65914 gyrocompass filter should be installed in the master-repeater transmitter to eliminate induction noise from the transmitter contacts.

If the 105-A direction finder is installed without the Sperry equipment, the 6.3-volt lamps originally supplied are used for illumination and the bearing scale set by hand to the desired reading by means of its setting knob.

Care should be taken in selecting the position for installing the apparatus in order to have a clear space around the loop free from large metallic objects which may affect the calibration of the loop. The stays and rigging of the ship should be studied for closed loops which may also affect the calibration and insulators, or bonding should be employed wherever necessary. At the same time, proper consideration should be given to the location of the binnacle in the pilot house or chart room.

The sense antenna for this direction finder should be 15 to 25 ft. in length, as nearly vertical as possible, and rigged as far away from existing stays of the vessel as conditions of installation will permit.

The maximum length of the sense antenna may be checked by observing the action of the balance condenser. If the antenna is too long, the balance will be extremely critical, making it difficult to take bearings. Shortening the antenna by a few feet will generally obviate this difficulty.

b. 105-A Direction-finder Features. Loop.—27 in. diameter shielded and balanced. Inductance 325 μ h at 1,000 cycles. Distributed capacity — 100 mmf. at radio frequencies. $Q = 160$ at 500 kc. $Q = 200$ at 255 kc. all for complete loop measured at receiver terminal board.

Indicator: Automatic type with full-vision dial. Maximum correction plus and minus 22 degrees by means of cam cut at installation. Low-loss collector ring and brush assembly designed for freedom from noise and corrosion are located in an indicator housing where they are protected from moisture, condensation, and dirt.

Binnacle: Heavy aluminum, federal-gray finish.

Condensation: Provision is made to prevent accumulation of moisture, which might be caused by condensation or leakage, by adequate system of drainage. Loop housing and bearings are carefully weatherproofed to prevent entrance of moisture into direction-finder structure.

Circuit: 8 tube TRF with push-pull input and 6.3-volt heater tubes. Completely shielded.

Frequency Range: 255 to 550 kilocycles.

Sensitivity: Average better than $0.25 \mu\text{v}$ for 6-mm. output measured through loop at above frequencies.

Selectivity: Band width measured at ratios of input voltage off resonance to input voltage at resonance.

Ratio	Band Width in Per Cent Resonant Frequency
10	Less than $1\frac{1}{2}$
100	Less than 3
1,000	Less than 6

Fidelity: Flat within 4 db from 200 to 1,500 cycles, down 11 db at 100 cycles, and down 15 db at 5,000 cycles.

Output Impedance: 20,000 ohms at 1,000 cycles.

Volume Control: Wide range by control of screen voltage down to 0 volts. Signals of 1-volt intensity can be easily handled.

Balance Control: Capacity type with double-stator condenser.

Sense Indication: Separate non-locking push-button switch.

Beat Oscillator: Separate tube with control switch.

OFF-ON Switch: Breaks both *A* and *B* circuits.

Relay: 6-volt interlock relay operated from radio room.

Batteries: One 6-volt storage battery, current drain 3.15 amp., charging rate 3.5 amp.

Two 45-volt *B* batteries, current drain 15 ma maximum.

Signaling System: Relay in receiver operated by antenna switch in radio room makes use of receiver impossible unless transmitting-antenna switch is opened.

c. Maintenance.—Routine inspection of the apparatus should be made about once a week. All battery voltages should be checked with the receiver in operation and, if necessary, the storage battery placed on charge and water added. The *B* batteries should be replaced if they measure less than 38 volts each under load.

The following accessories may have to be replaced over a period of time:

Four 6D6 vacuum tubes.

Two 76 vacuum tubes.

Two 37 vacuum tubes.

Two 45 volt *B* batteries, Burgess No. 10308.

One 6-volt storage battery, Exide No. 3LXL-7.

Five 6-volt lamps, Mazda No. 40.

The lubrication of the equipment should be inspected every 6 months and replenished if necessary. The oil cup on the upper loop bearing should be filled with medium machine oil. The two grease cups on the indicator bearings should be screwed in one-half turn. When the grease cups are empty, the caps should be removed and filled with medium cup grease.

Care should be taken to prevent an excess of lubricant from running out of the bearings.

If the collector rings become dirty, they may be polished with *very fine sandpaper* or crocus cloth, after wiping clean with alcohol. *Do not use emery paper.*

The equipment should also be inspected mechanically to make certain that no screws or other fastenings have been loosened by vibration or damage.

Troubles and Remedies.—Although the design of the apparatus is such that continuous and reliable operation should be obtained, the following list may help in the diagnosis of any difficulty encountered in the use and care of the instrument.

Symptom	Cause	Remedy
1. No <i>A</i> voltage	Battery on charge	Throw switch to "Receive"
2. Low <i>A</i> voltage	Battery dead	Throw switch to "Charge"
3. <i>A</i> battery will not charge	Blown fuses or reversed direct-current supply	Replace fuses, check polarity of direct-current supply
4. No <i>B</i> voltage	Blown fuse lamp	Clear short then replace lamp
5. Low <i>B</i> voltage	<i>B</i> batteries dead	Replace <i>B</i> batteries
6. Panel lamp out	1, 2 or burned out lamp	Replace lamp
7. Signal lamps will not light. Relay will not operate. Tubes will not light	1, 2, 6 or antenna switch closed or out of order	Open ant. switch in radio room. Check and repair antenna switch. Check cable between radio room and radio direction finder.
8. No signal	1, 2, 4, 5, 7 or defective tube, volume control, resistor, radio-frequency or audio-frequency transformer, condenser, phones, jack, short-circuit or disconnection	Check tubes, phones and general circuit for continuity and shorts
9. Weak signals (see Par. 15)	2, 5, or above	Same as above
10. No balance action	Short or open in loop, antenna or balance condenser	Check and repair
11. No "sense" action	Defective switch or open "sense" resistor or short or open in "sense" antenna	Check and repair
12. No beat note	Open beat oscillator resistor, defective switch or shorted by-pass condenser or defective oscillator coil or tube	Check and repair
13. Audio whistle	Low <i>B</i> batteries, open <i>B</i> + by-pass condenser	Check and replace <i>B</i> batteries or condenser
14. No radio-frequency oscillation	Open by-pass condenser or defective resistor	Check and repair

15. *Broad Tuning.*—In case it is suspected that the receiver tuned circuits are out of alignment, the following procedure should be followed. Remove the receiver panel by taking off the four nuts on the jack and switches, take off the knobs and the two screws on each side of the panel. The two condenser gangs should be lined up so that the rotor plates of each are *exactly* flush with the stator plates at the position of maximum capacity. This adjustment is made fixed by the set screws in the insulated coupling between the two gangs. The drum dial should then be set so that the scale reads 0 with the condenser gangs at the maximum position. This adjustment is made fixed by the square head set screws in the hub of the drum dial. Assemble the receiver and replace in the cabinet and adjust the trimmers on top of the gang for maximum output on a 500-kilocycle signal with the dial set at 72.5. The loop adjusting condenser located underneath the chassis should also be adjusted at this frequency and then checked at 300 kilocycles. If the position of this unit varies, it should be set halfway between the two tuning points. The beat oscillator trimmer (on the extreme right) should be set to give a beat note on all tuning frequencies throughout the scale.

16. *Calibration.*—The mechanical calibration of the direction finder may be checked by comparing the readings of the direction pointer and the checking scale on the hand wheel to see if the difference agrees with the original calibration data. If any change has been made in the rigging or structure of the vessel, it may be necessary to recalibrate the direction finder, or at least check the radio calibration by several simultaneous radio and sight bearings taken on a radio beacon at several points around the indicator dial.

In cases of erratic bearings, look for intermittent grounds or open circuits in the rigging or antennas on the vessel. Broad bearings may be observed if the main transmitting antenna is grounded.

17. *Noises.*—Noise in the receiver itself may be caused by loose battery connections, broken wires, poor contact of a tube in its socket, or by a *B* battery fuse lamp loose in the socket.

Noise observed when the loop is rotated rapidly may be caused by dirty collector rings and should be corrected by cleaning the rings as stated above under maintenance.

Induction noises from electrical machinery on the vessel should be traced to the machine causing the trouble and filter condensers connected across motor commutators or other spark-producing elements.

16.7. Marine Aircraft Direction Finders. 1. COAST GUARD TYPE.—An aircraft radio direction finder manufactured for the United States Coast Guard is shown schematically in Fig. 16-10. This type, known as model CGR-19-D, is designed for use on heavier-than-air Coast Guard craft where a radio operator is available for taking radio bearings. The various units comprising the equipment are all mounted within easy reach of the operator and so located that the receiver may be used in conjunction with the transmitter for communication purposes if desired. The antenna connects to the circuit through a jack mounted on the receiver panel and is easily connected or disconnected as desired. The center of the loop is grounded to provide a bias for the grid of the radio-frequency amplifier tube.

A balanced radio-frequency input to the receiver is not necessary because of the absence of residual signal and deviation on a loop installed aboard an aircraft. In other respects, this direction finder is similar in

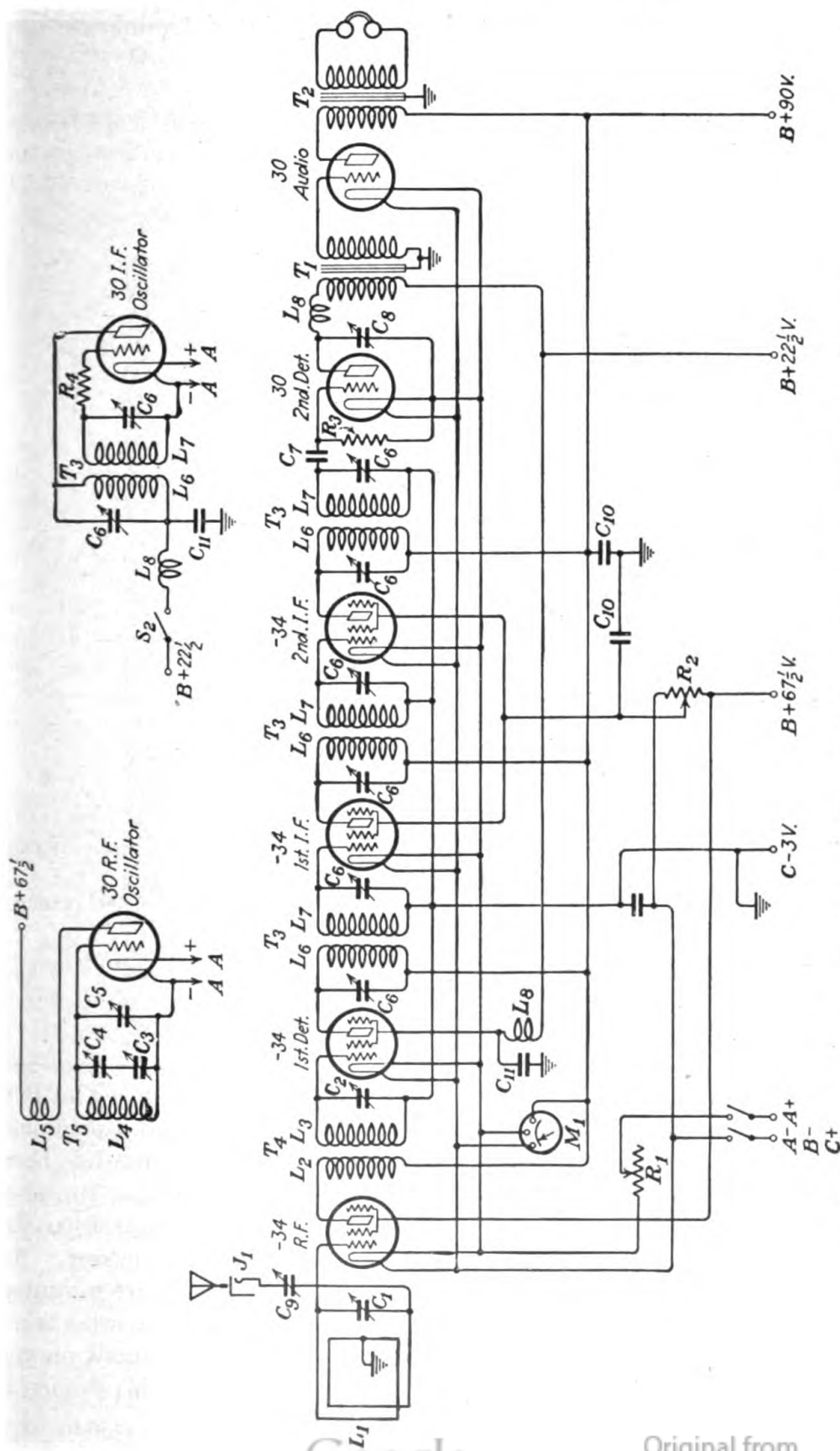


FIG. 16-10.—Radio direction finder; C.G. model CGR-19-D. (Courtesy of U.S. Coast Guard.)

principle to the conventional direction finder designed for marine use, except that it is much smaller in size.

PARTS OF RADIO DIRECTION FINDER, AIRCRAFT TYPE UNITED STATES COAST GUARD,
MODEL CGR-19-D (See Fig. 16-10)

- C_1 Loop tuning condenser, 0.00126 mf.
 - C_2 } R.-F. tuning and r.-f. oscillator condenser, each section 0.00041 mf.
 - C_3 }
 - C_4 R.-F. oscillator padding condenser, 0.001 mf.
 - C_5 R.-F. oscillator trimming condenser, 0.00014 mf.
 - C_6 I.-F. transformer trimming condenser, 0.00014 mf.
 - C_7 Second detector grid condenser, 0.00025 mf.
 - C_8 Second detector plate by-pass condenser, 0.002 mf.
 - C_9 Antenna adjusting condenser, 0.00070 mf.
 - C_{10} By-pass condenser 250-volt non-inductive type, 2 mf.
 - C_{11} Filter condenser, 0.1 mf.
 - J_1 Antenna jack, open-circuit type.
 - L_1 Loop winding, 350 μ h.
 - L_2 R.-F. transformer, primary, 410 μ h.
 - L_3 R.-F. transformer, secondary, 1,065 μ h.
 - L_4 R.-F. oscillator, grid winding, 440 μ h.
 - L_5 R.-F. oscillator, plate winding, 48 μ h.
 - L_6 I.-F. transformer, primary and secondary windings, each 6.5 mh.
 - L_7 I.-F. oscillator, primary and secondary windings, each, 5.25 mh.
 - L_8 R.-F. choke, honeycomb wound, 15 mh.
 - R_1 Filament rheostat, 6 ohms.
 - R_2 Volume control, 500,000 ohms.
 - R_3 Second detector grid, $\frac{1}{2}$ -watt size, 2 megohms.
 - R_4 I.-F. oscillator-grid suppressor, $\frac{1}{4}$ -watt size, carbon, 6,000 ohms.
 - S_2 C-W jack switch.
 - T_1 Interstage audio transformer: primary turns 5,100; secondary turns 18,000; primary resistance 2,000 ohms; secondary resistance, 9,000 ohms.
 - T_2 Output audio transformer: primary turns 5,075; secondary turns 5,500; primary resistance 1,000 ohms; secondary resistance 1,500 ohms.
 - T_3 I.-F. unit and intermediate-frequency oscillator unit, 175 kilocycles.
 - T_4 R.-F. amplifying transformer.
 - T_5 R.-F. oscillator transformer.
 - M_1 Meter, double range 150–7.5 volts, d.c., with push button.
-

2. PAN AMERICAN AIRWAYS CLIPPER DIRECTION FINDER.—The Pan American Airways utilize a specially designed type of radio direction finder in which the heavy pedestal found on shipboard models has been eliminated to save weight. In this direction-finder apparatus, the loop assembly is mounted on a supporting base, which is clamped to the "ceiling" of the radio room through which the loop shaft passes. An indicating dial and a small hand wheel for turning the loop are mounted inside the radio room within easy reach of the radio operator, who takes the bearings, as shown in Fig. 16-11. The receiver is mounted on the operating table as shown. The principle of operation of this device is the same as for the types previously explained.

16.8. Calibration. *a. Requirements.*—The radio direction finder must be calibrated before it is ready for operation. This means that the direction-finder readings must be compared with true magnetic bearings and permanently recorded for the use of the operator or navigator in setting and checking the mechanical compensator, or, if such a compensator is not fitted to the direction finder, for use in converting direction-finder bearings to true bearings.



FIG. 16-11.—Radio officer aboard transatlantic clipper. (Courtesy of Pan American Airways Corporation.)

The procedure followed in calibrating a radio direction finder aboard a vessel differs in detail from the procedure followed in calibrating a direction-finder installation located ashore or on a seagoing heavier-than-air craft. Essentially, however, the method is the same in that it involves the taking of simultaneous sight and radio bearings and recording the results.

When a navigator on a vessel utilizes a radio bearing supplied by a radio direction-finder station located ashore, it is necessary that he know the exact geographical location of the shore station at which the bearing was measured. This information is to be found together with other

pertinent data in the official list of Direction-Finding Stations published by the government and referred to before. For this reason, therefore, it is necessary when calibrating a radio direction-finder station located on land that the exact geographical location of the station be determined in degrees, minutes, and seconds of latitude and longitude. This requires an accurate survey map of the vicinity indicating the location of prominent objects such as tall buildings, church spires, standpipes, lighthouses, and the like, by means of which the station location and true north can be determined.¹

The actual calibration of a radio direction finder is usually done by someone especially trained for this work. Once the direction finder has been calibrated, no one should tamper with the mechanism.

b. Calibrating a Direction Finder Which Has Been Installed on a Vessel.—The procedure required is to swing the vessel in azimuth while taking simultaneous radio and pelorus observations. These observations are recorded in two comparative columns, their differences noted, and a calibration curve of plus or minus errors against the direction-finder reading is plotted. Readings are taken from the calibration curve at every 15 degrees, the mechanical compensator (if provided) adjusted accordingly, or the variations are transferred to a corrector disk. As the accuracy of the direction finder after calibration depends directly on the accuracy of the visual observations made at the time of calibration, these observations must be made with the utmost care.

It is obvious that the radio direction finder cannot be calibrated while the vessel is in dock. This operation is usually carried out in open water (for example, off Ambrose Lightship in the New York area), and, at the time of calibration, all davits, booms, searchlights, and any other large metallic objects in the vicinity of the direction finder must be stowed in their normal position for sea and left that way throughout calibration. Changes of any extensive nature made in the location or trim of any of these surrounding objects might induce an error in the direction finder. This especially applies to large searchlights which are sometimes mounted close to the loop and which, when not in use, should be kept trimmed in their regular position. Stays and guys should be left in the condition in which they were at the time of calibration, that is, ungrounded, or grounded to the ship's hull by jumpers. To ground an ungrounded stay, or vice versa, after the direction finder has been calibrated is likely to introduce an error.

The calibration of the direction finder may be checked from time to time for accuracy by taking simultaneous pelorus and radio bearings when in the vicinity of light vessels equipped with radio beacons, or when in visual range of any vessel capable of transmitting the required

¹ Various methods of locating true north are described in detail in "Wireless Direction Finding and Directional Reception," by R. Keen, Iliffe & Sons, Ltd., London.

signals. Signals used for calibrating purposes, or for checking calibrations, should be about 3 or 4 miles distant. At least 4 miles is preferred so that any possible error due to parallax (wave distortion) may be minimized.

Marine-type radio direction finders, such as are described in this chapter, are simple to operate, but considerable practice is required before the observer can become proficient and skillful in taking quick and accurate bearings under all conditions.

c. Calibrating a Direction Finder Installed at a Shore Station.—This operation requires that the procedure described before, for calibrating a direction finder installed on a vessel, be reversed. It is obvious that the shore station cannot be moved and that necessarily the source of signal must be moved instead. Calibration under these conditions is usually carried out by utilizing a radio transmitter located on a small vessel which can be moved around in azimuth to the direction finder which is fixed in position. Sight and radio bearings are taken in the usual manner from true north as a reference. A transit or theodolite is required for taking the visual bearings.

For calibration purposes the transmitting signal should be modulated.

d. Calibration on Aircraft.—In general, the procedure for calibrating a radio direction finder of the manual type installed on a seagoing aircraft is similar to the method of calibrating a direction finder installed on a vessel except that the calibration must be done with the plane on a landing field and not on the water. The work must be done with the craft located well away from conducting wires or structures and with no intervening objects between transmitter and receiver. Near-by or intervening objects may produce wave-front distortion resulting in false radio bearings. The transmitter must be located so that its signal does not pass closely parallel or oblique to the shore line or across intervening objects. The effect of all transmitting and receiving antennas on deviation must be determined at the time of calibration. Those antennas found to affect the deviation must be *open* (not *grounded*) during calibration and when taking bearings thereafter.

For the transmitting station or target a medium-powered transmitter emitting modulated waves and located on a small patrol boat should be employed. The calibration should be made at, or close to, the frequency to be most used. On a properly designed direction finder the calibration will probably hold quite well over the entire frequency band, but, if closer accuracy is desired, a calibration should be made at each end of the band. The aircraft must be insulated from the ground with the tail elevated to flying level by a cart or dolly. The motive power for accomplishing the swinging may be a tractor or its equivalent.

For taking the simultaneous visual bearings, a pelorus must be securely mounted on some part of the plane where azimuth sights may

be made throughout 360 degrees. The zero of the pelorus should be set on the dead-ahead position, or lubber's line.

When the head of the ship is swung into approximately the zero position, the radio observer obtains a null on the transmitter and calls out "mark." The visual observer at the pelorus notes his bearing, and both observers give their readings to the recorder. The difference between readings determines the error. Swing the tail of the ship about 5 degrees and repeat the readings. Continue with this until the ship has been turned around 360 degrees. Calibration made with the aircraft on the water must be regarded as approximate and not sufficiently accurate for navigational purposes.

Any deviation from true bearings should be recorded and transferred to a calibration chart (or mechanical compensator if provided), using the radio bearings as abscissas and the difference between pelorus and direction-finder readings as ordinates. Deviation varies on different types of aircraft owing to the difference in the locations of closed loops formed by struts and bracing in the frame.

16.9. Operation.—The first rule in the operation of the radio direction finder is: NEVER USE THE DIRECTION FINDER WHILE THE MAIN ANTENNA IS IN USE OR GROUNDED. To guard against accidental or unintentional violation of this rule a radio direction finder designed for use on a large vessel, where the direction finder is located in the chart room or pilot house, is provided with an interlock switch arrangement between the direction finder and an antenna-opening switch in the radio room. A signal light in the radio room notifies the radio operator when the direction finder is in use. This interlock renders the direction finder inoperative unless the antenna switch in the radio room is open.

If the radio direction finder is located in the chart room or pilot house, the navigator, when wishing to use the direction finder, directs the radio operator to open (not ground) the main antenna. Other antennas may be left connected in their normal operating condition provided they are not tuned within 1,500 kilocycles of the observed signal frequency. *Any equipment used with these antennas should not be tuned or adjusted while the direction finder is in use.* To take a bearing with the main antenna in use or grounded might result in damage to the direction finder or in an erroneous observation being made. This is due to the direct effect of the main antenna field in which the direction-finder loop is usually located. The grounding or using of the main antenna while taking a bearing is usually indicated by a strong residual signal existing in the null area and an abnormal balancer adjustment.

The actual operation of a radio direction finder is substantially in accordance with the following operations:

a. Getting the Line of Direction.—1. Start the receiver operating by inserting the telephones in the jack and operating the proper switches in accordance with the requirements for the particular set in use.

2. Tune in the source signal (signal on which bearing is to be taken) by varying tuning control on receiver to desired frequency and by orienting loop until maximum signal is heard. If volume is too great, decrease it, by decreasing filament voltage or by operating volume control, if supplied. Do not decrease volume by detuning receiver as this may result in erroneous bearings.

3. Swing the loop approximately 90 degrees from the position of maximum signal which should bring it to the area of minimum signal audibility. If a parallel-line indicator is provided, observe from proper end. This is the end which was used during calibration. On the plate-glass type it is indicated by an arrowhead. Swing the loop back and forth over this restricted area, while at the same time adjusting the control marked *BALANCE*, until a point is found where the signal strength is zero or nearly zero. Set the loop at the center of this null area. Read the desired bearing from the indicator. If the observed signal is from a distant source and is weak, the null will be broad. In this situation increase the filament voltage to normal, or bring up the volume by operation of the volume control if heater-type tubes are used. Conversely, a very strong signal from a near-by transmitter will give an exceedingly sharp null which may be confined to a fraction of a degree in width. On exceptionally loud signals, it may be necessary to decrease the volume considerably in order to discern the area of minimum signal intensity. If filament-type tubes are used, care must be taken not to decrease the filament voltage so low that the receiver becomes inoperative. If the null extends over a considerable range, it will be necessary to note two points, one on each side of the silent area, where the signal becomes of equal audibility or intensity, taking the *mean* of these two points as the bearing.

On some direction finders, owing to local effects and the characteristic of the signal under observation, it may be impossible to obtain an absolute null as the indicator is swung through the minimum area. When this condition exists the bearing will be taken from the estimated center of the area of minimum signal intensity. This condition is shown in Fig. 7-35.

The quality and definition of the null will vary on a given signal, as it is observed from various headings. This is due to the effect on the incoming signal by local metallic agents such as stays, guys, and riggings. This effect has been explained in detail under Sec. 16.5 on Reducing Deviation. It may now be said, however, that at times the residual quality of an observed signal may be too strong for complete extinction.

The radio bearing indicated by the point of minimum signal on the scale is either the true bearing from the observing station or its reciprocal. For example, if a minimum signal is observed when the indicator points to 60 degrees, another minimum signal will be observed when the indicator points to 240 degrees. Unless the observer knows positively on which side of the compass the transmitted signal lies, he would have no way of telling which of these bearings was the true bearing. This difficulty is eliminated by utilizing the unilateral characteristics of the loop when used in conjunction with a non-directional antenna and is called *getting a sense bearing*. This operation follows next in order.

b. Getting the Sense of Direction.—1. Swing loop approximately 90 degrees from point of null position, and throw switch to *sense* position (or push *SENSE* button, if supplied instead of switch), noting signal strength. Then turn loop approximately 180 degrees (sense switch or button still in) and note signal strength. It will be noted that the signal is stronger in one 90-degree (from null point) position than in the other. On the conventional type of marine direction finder found on large vessels the quadrant in which the true bearing lies will be indicated by the position of a pointer (usually red) when the loudest or maximum signal strength is obtained with the sense switch on.

Another method of obtaining the sense of direction is as follows: The true bearing is indicated by the way in which the loop is turned for maximum signal. If the

position of strongest signal occurs when the front side of the indicator moves in a clockwise direction, the bearing as indicated on the indicator scale is correct. Otherwise, the bearing is the reciprocal, the loop should be turned 180 degrees, and the correct bearing determined by a new point of minimum signal which should be the reciprocal of the first bearing observed.

In obtaining sense bearings the sense effect will be more apparent if the sense connection within the circuit is made intermittently, rather than closed permanently, while swinging the loop through the area of maximum signal intensities. This can be done by rotating the knob controlling the sense switch to the sense position several times during the sense operation or by pushing and releasing several times a sense button provided on some types of direction finders for this purpose.

2. The true bearing, as indicated by the proper null point, should have added or subtracted to or from it the necessary correction factor unless this operation is automatically done by a mechanical compensator.

3. If bearings are to be taken on *C-W* signals, the *C-W* control switch must be closed. On direction-finder equipments provided with superheterodyne receivers this *C-W* switch starts the *C-W* oscillator which beats against the incoming signal making it audible. On direction-finder equipments not fitted with superheterodyne receivers this switch closes a feed-back circuit on the detector causing it to operate as a regenerative detector and thus making it capable of receiving *C-W* signals.

4. If the direction finder is located in the chart room or pilot house and used by the navigator directly, he should notify the radio room when he is finished with the direction finder so that the main antenna may be placed back in service. This is usually done automatically by interconnected signal lights.

16.10. Fixing the Position.—The operation of fixing the position of a vessel or aircraft, after the radio bearings have been taken, is called plotting a "fix" and is strictly a navigational function. It is not generally done by the radio operator but is performed by the captain or another navigating officer.

Figure 16-12 illustrates a method by which a ship approaching New York harbor might fix its position. In this method two bearings are taken, one from Ambrose Channel Lightship, and the other from Fire Island Lightship. In the illustration it is found that Ambrose Channel Lightship is 20 degrees off the port bow (to the left) and that Fire Island Lightship lies 40 degrees off the starboard bow (to the right). By applying navigational deductions and plotting the lines on a chart, the position of the observing station is at the point where these lines cross. A third bearing might be taken, as for example from the Sea Girt Light Station, as shown in the diagram, to increase the accuracy of the "fix."

Another method is to take two bearings from a single source. This taken with the distance traveled may be solved as a triangle problem by trigonometry. For example, in the triangle in Fig. 16-13, let *A* be the source of signal or the transmitting beacon; let *B* be the position of the ship when the first bearing was taken, let *C* be the position of the ship when the second bearing is taken; *a* is the distance between *B* and *C* or the miles logged, and *b* is the distance from the source *A* to the observer *C*. Then, $b = (a \cdot \sin B / \sin A)$. The entire problem is worked with the

aid of a navigation chart and the exact position of the observer easily marked off.

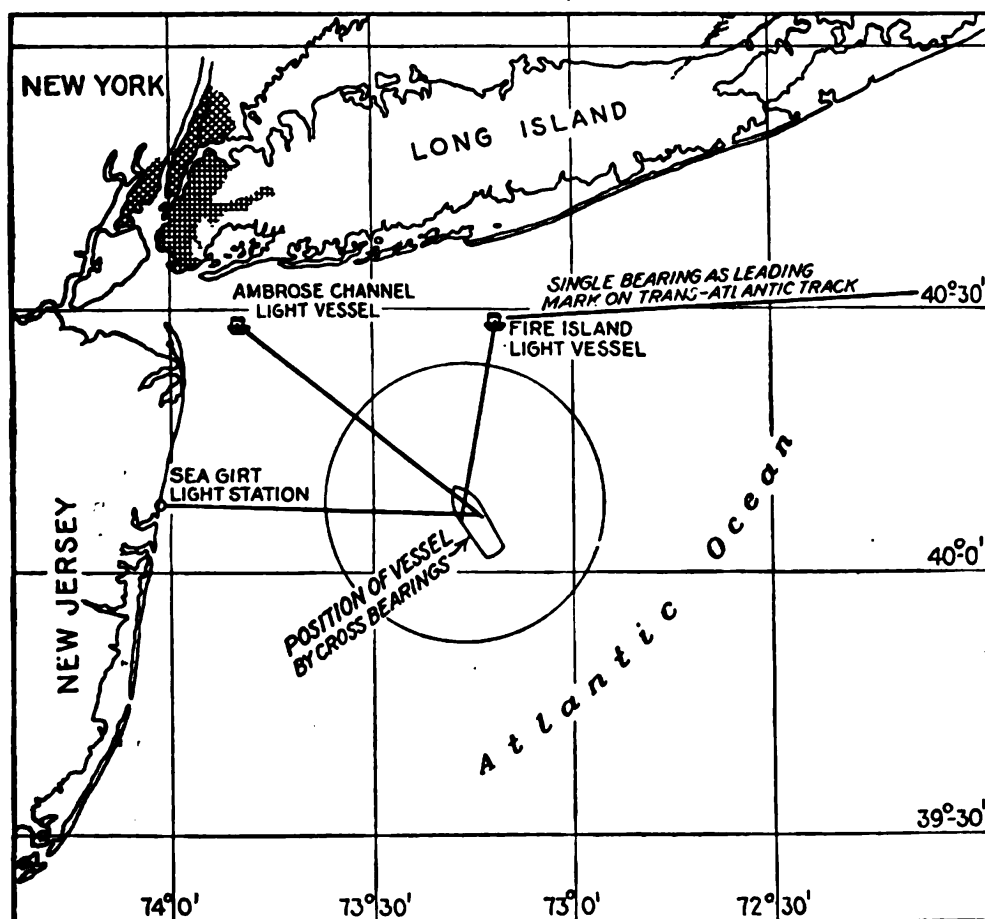


FIG. 16-12.—Method of plotting position from radio bearings.

In a similar manner radio direction-finder stations located on the shore can take simultaneous bearings on a vessel equipped with a trans-

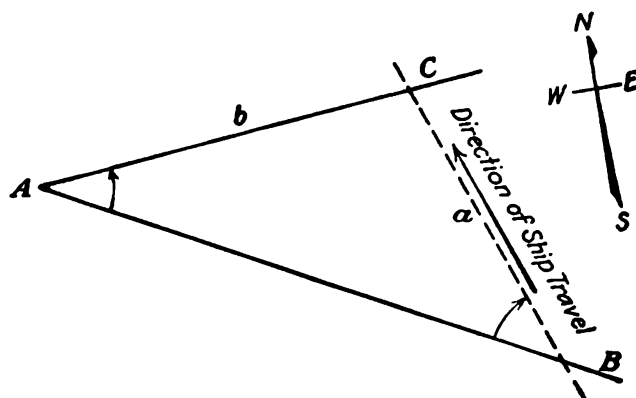


FIG. 16-13.—Position plotting by two bearings from a single source.

mitter which bearings can be plotted on a chart on which the position of the vessel will be indicated by the point of intersection of the lines if

the triangulation method is used, or by trigonometrical deduction if the second method is used.

If three or more bearings are taken on a ship by three or more well-separated shore stations, the lines will in nearly every case form a small triangle by their points of intersection. The center of this triangle is regarded as the location of the vessel. The only direction-finder stations located on the shore are those maintained by the United States Navy and the United States Coast Guard; the latter does not furnish bearings to ships as a regular procedure unless distress or emergency conditions are involved. At all these stations only operators especially trained for this duty furnish navigational bearings.

16.11. Maintenance. *a. General.*—Routine inspection of the direction-finder apparatus should be made at least once each week. During this inspection measure the voltage of the *A* and *B* batteries with the set turned on. Unless the *B* battery is on trickle charge, measure the gravity of each cell, and charge if necessary. *B* batteries should be replaced when the voltage has dropped 15 or 20 volts for the entire bank. *C* batteries should be replaced at the same time.

Test receiver for response to signals. Low sensitivity may be due to one or more defective tubes which may be detected by replacing each tube independently until signal response is normal.

Inspect the lubrication every 3 months and if required add a small amount of grease at the proper points.

Rotate loop by a series of jerks while the receiver is in operation to test slip rings for noisy contact. If these contacts are found to be noisy, clean with canvas or fine sandpaper.

When a vessel is in port and there are probabilities of the ship's power being shut off, it is advisable to disconnect the filament battery in the event of a polarity reversal when the power is again put on. It is recommended here that all operators should test for proper polarity before reconnecting, in order to avoid the possibility of ruining the storage battery. Serious consequences in a case of this kind may result.

b. Aircraft Direction-finder Maintenance.—In addition to the points of general maintenance outlined above, the direction finder installed on an aircraft deserves special consideration. Check the receiver for operation by listening to any available signals. The *C-W* switch gives a squeal on broadcast or other *C-W* carriers. Turn the loop to determine if nulls are obtainable on the various signals heard. Do not assume that directions of signal sources heard while the ship is in the hangar are correct. Usually, under these conditions, there will be large errors, and, possibly, all signals will come in on approximately the same bearing. This condition is due to the metal framing in or about the hangar. Observed signal intensities will be found much lower when the ship is in the hangar than when it is in the open.

If changes are made at any time in the framing of the wings, or if wiring is added to or removed from the ship, the calibration of the direction finder must be checked. When doing this, it is necessary to check only on a few points, especially those where the greatest errors occur.

16.12. Troubles and Remedies.—*a.* If the filament voltmeter does not read, check filament battery.

b. If the filament voltmeter reads correctly, but the receiver sounds dead, inspect as follows:

1. Check all *B* and *C* battery connections.
2. Look for poor tube.
3. Check wiring of receiver with aid of diagram.
4. Inspect contacts at collector rings.
5. See that no plate-circuit fuses or fuse lamps are blown

c. If receiver is noisy, look for loose connection at battery connections and at collector rings. Noise is very often caused by defective or weak *B* batteries or by a poor phone-jack contact.

d. The entire absence of directional effect may be caused by the loop circuit becoming grounded. Moisture deposit, even if very slight, in the loop-collector-ring housing may ground the loop circuit. An open-loop circuit will also result in no directional effect.

e. Troubles that might develop in the wiring of the receiver can be located by tracing out the leads as shown in the wiring diagram of the set, supplied with the equipment. Any special directions given in the instructions applying to the particular equipment should be explicitly followed.

CHAPTER 17

MOTORS AND GENERATORS

Many radio transmitters are dependent upon the power supplied by dynamo-electric machines. Hence, a study of motors and generators becomes a requisite in any consideration of radio-communication systems. In this chapter, therefore, applications of the dynamo-electric principle to modern power-supply apparatus will be examined.

I. GENERATORS

A generator is a machine for converting mechanical energy into electrical energy. It must be driven by a prime mover which may take the form of a hand- or wind-driven machine, a steam, gas, or oil engine, or an electric motor, the combination being called a *motor-generator*, which machine is commonly employed in radio practice.

17.1. Types of Alternators. *a. Introduction.*—The principles of operation of the simple alternator were fully treated in Sec. 2.1. The practical alternating-current generator or *alternator* is made in three distinct types: (1) the revolving-armature type, (2) the revolving-field type, and (3) the inductor type. The revolving-armature type of machine is usually a low-power machine owing to the difficulty of taking off heavy current from the revolving armature. Some of the old-type spark transmitters, such as the Marconi type P-4 or P-8, later converted into a tube transmitter and called the RCA type ET-3628, employ a G.E. 2-kw. revolving-armature-type generator. This type of machine has been almost wholly superseded by the inductor-type machine for low-power radio requirements. High-power alternators for power purposes are generally of the revolving-field type.

b. The revolving-armature type has the field poles fastened directly to the frame which, in turn, is bolted to the body casing or bedplate of the generator unit. The armature revolving in this field generates in itself an e.m.f. of alternating characteristics in a manner identical with the action of the simple loop in Fig. 2-1 in the chapter on Alternating-current Electricity. Current is taken from the machine by two slip rings and brushes as shown in the schematic construction diagram, Fig. 17-1.

c. The revolving-field type is generally used in large alternators in which high voltages are to be generated. This is shown in Fig. 17-2. Here the rotating field coils are excited by a constant e.m.f. and an alternating e.m.f. is induced in the stationary-pole armature windings as

soon as the field is rotated. Note the difference: in the stationary-field-type alternator the alternating e.m.f. is generated in the rotating armature winding and taken out to the external circuit by collector rings,

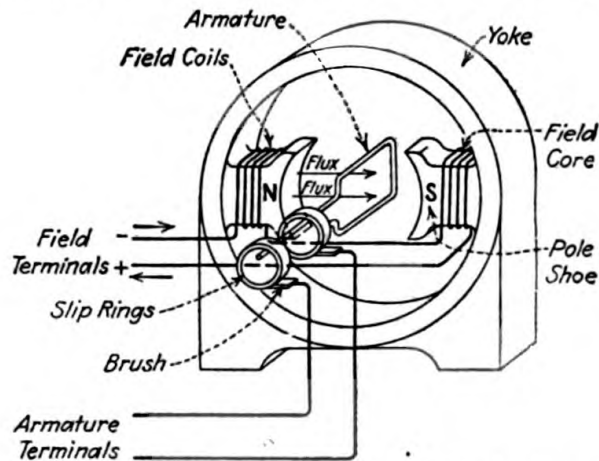


FIG. 17-1.—Mechanical arrangement of simple alternator.

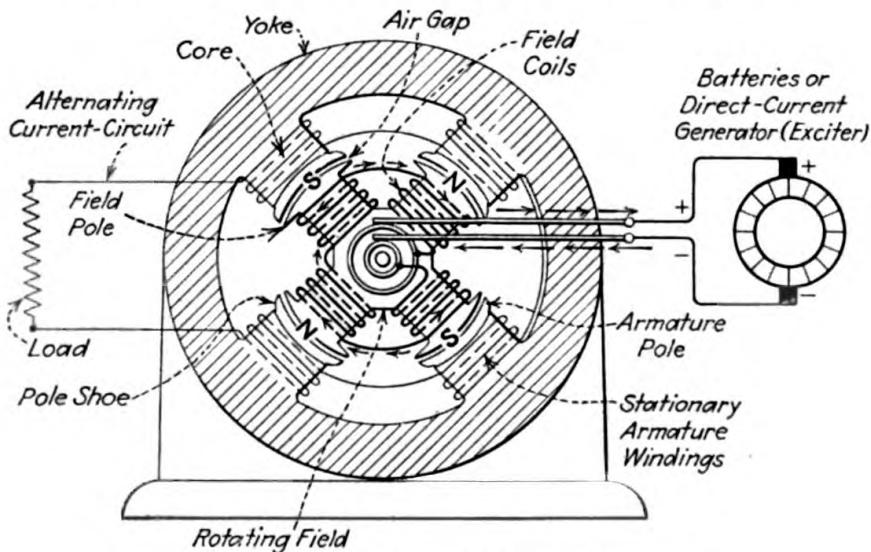


FIG. 17-2.—Revolving-field-type alternator.

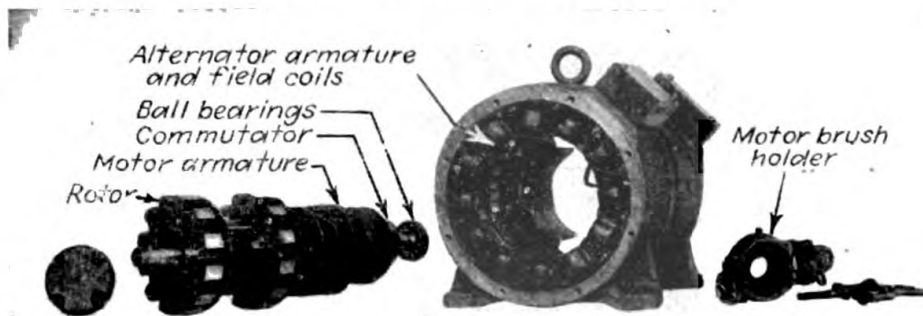


FIG. 17-3.—Parts of inductor-type alternator and motor-generator assembly.

whereas in the revolving-field type the alternating e.m.f. is taken out from the stationary-pole windings, now the armature, when the rotating field is excited by a direct current through collector rings. The student

will note that in either type of alternator the theory of induction holds true, that is, an e.m.f. may be induced into a conductor if the conductor is moved in a magnetic field, or an e.m.f. may be induced into a conductor if the conductor is placed in a moving magnetic field.

In the first type of alternator the alternating e.m.f. is generated in the armature if it is revolving in a properly excited stationary field, and the alternating current can then be taken from the armature by collector rings; and, similarly, an alternating current can be taken directly

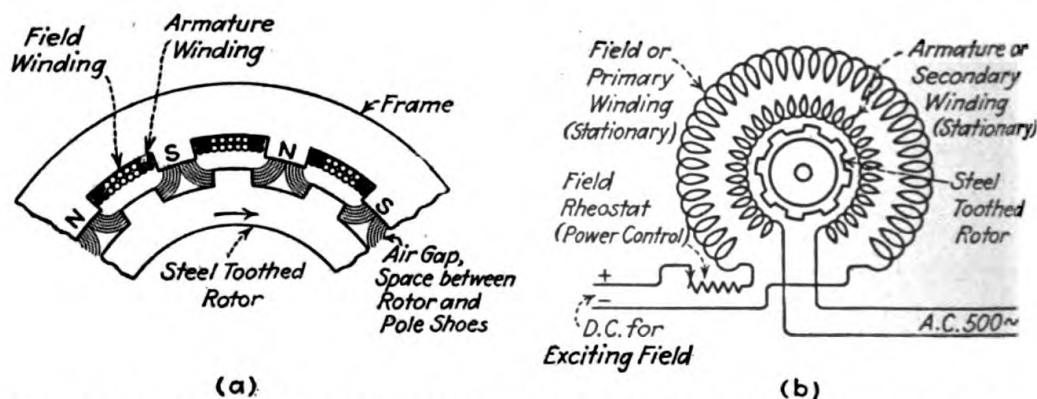


FIG. 17-4A.—Inductor-type alternator: (a) how rotor cuts flux; (b) schematic diagram.

from the stationary winding of the second type of alternator when the field is rotating around it, provided the rotating field is properly excited as in Fig. 17-2. In other words, the stator coils take the place of the rotating armature in this type and might be referred to as a *stator armature*. Actually the conductors are wound in slots cut into the frame of the machine in a manner similar to the scheme shown in Fig. 17-4A(a).

d. The Inductor Type.—In the inductor alternator the armature and field windings are fixed, but a revolving rotor of steel with toothed projections rotates in the magnetic path of both windings. This rotor

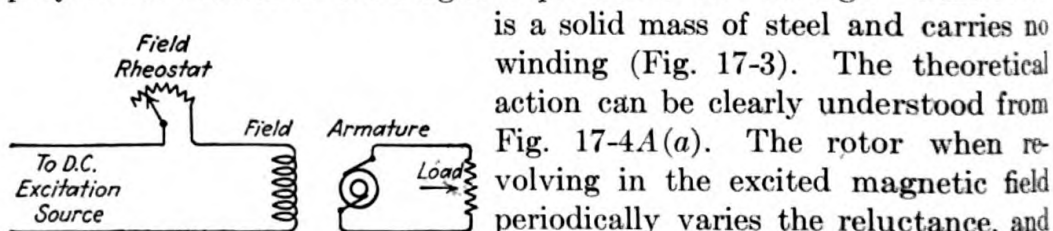


FIG. 17-4B.—Field rheostat (voltage control) connections on alternator.

is a solid mass of steel and carries no winding (Fig. 17-3). The theoretical action can be clearly understood from Fig. 17-4A(a). The rotor when revolving in the excited magnetic field periodically varies the reluctance, and thus produces a constant increasing and decreasing effect upon the magnetic flux. Therefore, when the flux is increasing, the induced e.m.f. will have a certain polarity. Then, upon decrease, the induced e.m.f. reverses and an alternating e.m.f. is generated. This type of design is used in practically all of the 500-cycle generators used with spark transmitters. A schematic diagram of the inductor-type alternator is shown in Fig. 17-4A(b).

17.2. Voltage Control on Alternators.—As most alternators are separately excited, it is a simple matter to regulate or control the output voltage by varying the excitation current. This is done by inserting a variable resistance in series with the field of the alternator, as shown in Fig. 17-4B. Such a control device is known as a *field rheostat*. Field rheostats for use with alternators usually have a resistance equal to about twice the resistance of the alternator field.

17.3. Direct-current Generators.—In many respects the direct-current generator is similar to the alternator, the principle of current generation in both machines being the same, that is, an e.m.f. is induced in the armature when the armature conductors are cut by the flux produced by the field of the machine. Also the e.m.f. induced in the armature of the direct-current machine is dependent upon the flux density in the field and the speed of cutting.

There are, however, two points of notable difference between the alternating-current and direct-current machine and these are: (1) the alternator may have a stationary or rotating field, or it may be an inductor-type machine, whereas the direct-current machine is always a rotating-armature machine; (2) the alternator is always fitted with slip rings (except the inductor-type machine), whereas the direct-current machine is always fitted with a commutator, the function of which will be explained later.

The parts of the direct-current machine are the *field*, the *armature*, and the *commutator*. The field is always stationary, the armature is always rotating, and the commutator is always necessary. The magnetic circuit of the direct-current machine is the same as that of the alternating-current machine, and the names of the magnetic circuit parts are similar.

Whereas alternating-current machines are nearly always separately excited, the direct-current machine is nearly always self-excited. For the same reasons that alternating-current machines are usually multipolar so, too, are direct-current machines multipolar.

It is evident from this summary of the similarities between the two machines that much of the theory of alternating-current machines also applies to direct-current machines. There are, however, some points of great difference which require special study. These points will now be explained.

17.4. Commutation.—It was seen in our study of the generation of an e.m.f. in a rotating loop that the current flow in the loop reversed itself once during each revolution of the loop. This caused the current to flow in a positive direction, let us say, when the loop was rotating in the arc from 0 to 180 degrees, and in the negative direction when the loop completed the revolution from 180 to 360 degrees. There was, therefore, a forward and backward flow for each revolution of the armature in Fig. 17-1 and this constituted the simple alternator.

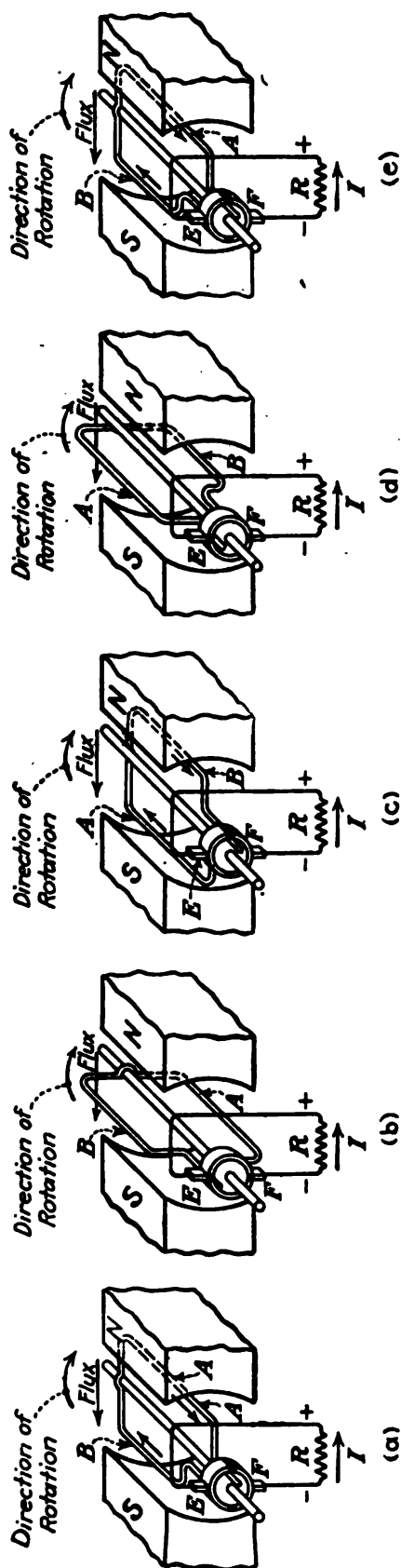


FIG. 17-5.—Commutator action through one complete revolution of the armature.

Now, in order to get a direct current at the output terminals of the machine, it is necessary to rectify this alternating current generated in the armature. This is accomplished in a generator by a commutator which, in the simple machine about to be explained, consists of two semi-circular current-collecting plates called *commutator bars* or segments fitted to one end of the armature as shown in Fig. 17-5. A commutator for a practical machine would have many bars, such as shown in Fig. 17-6. Large machines may have several hundred bars, but there are generally between 20 and 30 bars on small machines built for 110-volt circuits.

The function of the generator commutator is to reverse the connections of the armature conductors to the external circuit coincidentally with a change of induced e.m.f.s. in these conductors, as a study of commutation will show. If the loop in Fig. 17-5(a) is rotating in a clockwise direction, as indicated by the arrow, an e.m.f. will be induced in the loop and a current will flow in a direction along conductor A which would be toward the reader and along conductor B in a direction away from the reader. This is in accordance with the left-hand rule for revolving-armature machines explained in Sec. 1.35 on Production of E.M.F. by Field Cutting Conductor. From the conductor A the current flows through the external circuit R in the direction of the arrow. It is conducted to this circuit through the commutator bars attached to the conductors A and B, through the brushes making contact with these respective bars, and thence to the external-circuit line. Notice that the top brush is the positive terminal and the bottom brush the negative terminal of the generator.

Now, when the loop has made a quarter of a revolution [Fig. 17-5(b)], the conductors are running parallel with the magnetic field, are not cutting it, and, therefore, no e.m.f. is induced in the loop. At this moment the

brushes are making contact only with the insulated portion of the commutator while they are about to pass from one segment to the next, or, in this particular machine, to the opposite segment. When this is done [Fig. 17-5(c)], the connections to the external circuit from the conductors have been reversed, that is, conductor *A* is now connected to the top brush and conductor *B* to the bottom brush. In the first quarter of a revolution completed by the loop, the e.m.f. induced in the loop might be graphically shown to be from point *a* to point *b* on the voltage curve of Fig. 17-7.

As the rotation continues through the second quarter, conductor *A* proceeds to pass up in front of the south pole with the result that the current in this conductor is caused to flow in the opposite direction to the way it flowed when this conductor was passing the north pole. Also notice that conductor *B* is passing downward in front of the north pole, and that the direction of current flow is opposite to what it was when this conductor was passing up in front of the south pole [see Fig. 17-5(c)]. By carefully following the explanation just given, it will be seen that the current flow in the loop has reversed itself, and, as far as the loop alone is concerned, an alternating current has been generated. However, the commutator has also reversed the connections of the loop to the outside circuit, that is, conductor *A* is now connected to the top brush and conductor *B* to the bottom brush. These connections and direction of current flow continue as long as conductor *A* is passing up in front of the south pole and conductor *B* down in front of the north pole, or to the end of the third quarter.



FIG. 17-6.—Small-size commutator.

When the third quarter has been completed, the brushes again pass over the insulated section of the commutator from one bar to the next, reversing again the connections from the conductors to the external circuit. During the last quarter, conductor *A* is again connected to the bottom brush and conductor *B* to the top brush. Conditions are now the same as they were in the first quarter, and the revolution has been completed.

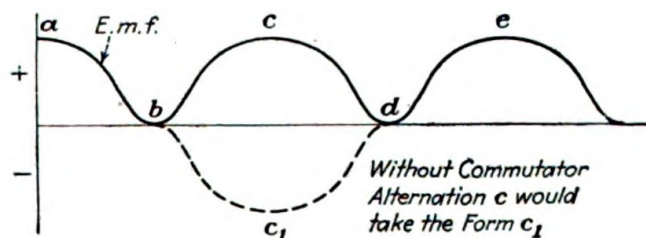


FIG. 17-7.—Effect of commutator on alternating current flowing in generator armature.

On the voltage curve (Fig. 17-7), point *b* to point *c* is the e.m.f. generated during the second quarter; point *c* to point *d*, during the third quarter; point *d* to point *e*, during the fourth quarter. Therefore, with a complete revolution of the loop, two pulses of direct current are sent into the external circuit. As the revolution of the armature continues, the pulses continue to flow in the external circuit and a direct current is being generated. Of course, in a practical machine there are many armature turns or loops, and many pulses are generated in a revolution giving the effect of a steady current of unvarying amplitude in the external circuit.

It is seen from this elementary explanation that the current in either conductor of the loop of the simple machine, shown in Fig. 17-5, is in a direction toward the reader when either conductor is passing down in front of the north pole; and away from the reader when either conductor is passing up in front of the south pole. Also

notice that the top brush is always connected to the conductor passing the south pole, and that the bottom brush is always connected to the conductor passing the north pole. As the direction of the current flowing in the conductor to which the top brush is connected at any given moment (except when the brushes are passing from one bar to the next over the insulated mica-segment portion of the commutator)

is always the same, it follows that a direct current must flow in the external circuit.

The principle of commutation just explained applies to all direct-current machines regardless of size or number of bars in the commutator.

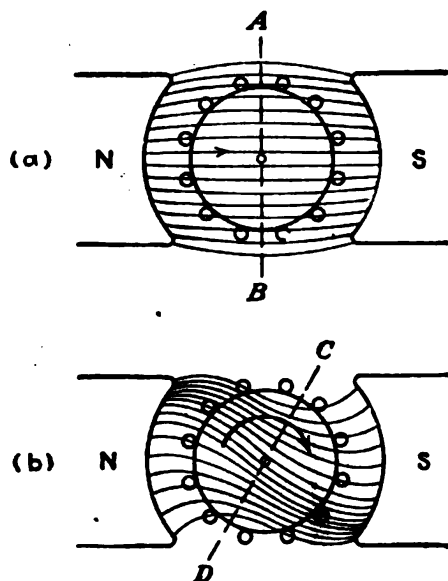


FIG. 17-8.—Effect of armature reaction.

that, for a generator, armature reaction tends to move the neutral axis in the direction of the rotation of the machine. In a motor this tendency is reversed, and the neutral axis is moved against the direction of rotation. For sparkless commutation the brushes must be set in the neutral axis. The reason for this is as follows:

In Fig. 17-9(a) is shown an armature element halfway between two adjacent poles. This is the position of neutral field when there is no field shift due to armature reaction

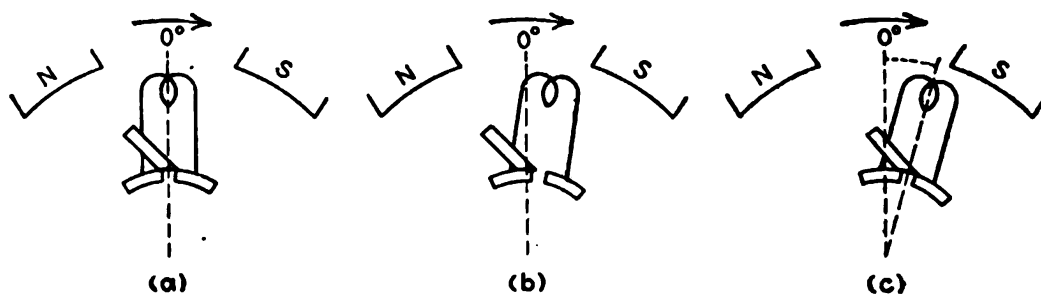


FIG. 17-9.—Graphical analysis of brush sparking.

an effect which need not be considered as affecting this explanation. As the coil is passing through the position of neutral field, no e.m.f. is being generated or induced in the coil. Furthermore, the brush short-circuits (by-passes) the coil, and no current flows from it. However, the self-inductance of the coil tends to maintain a current flow in the coil even though it is short-circuited. This current, by the way, is a north-pole-induced current and as such flows in a certain direction, which for the purpose of this explanation we shall call clockwise.

As the coil comes under the influence of the south pole (b), which induces a counter-clockwise current in the coil, there is a very sudden tendency for the clockwise current

which was due to the north pole to cease flowing. At this same instant the brush is breaking contact with the bars and ceasing to short-circuit them. It might be said at this point that the brush did not short-circuit the coil long enough for the clockwise current entirely to cease flowing, and, therefore, at the moment the brush is breaking contact with the bars, there is a relatively high current set up in the coil (by the sudden reduction of the clockwise current by the counterclockwise current), which causes an arc to form between the brush and the bar it is leaving. This arc constitutes what is commonly referred to as *sparking* and, besides being a direct power loss, soon ruins the commutator.

In small machines this sparking may not be severe, but in heavy-duty machines a method of reducing sparking at the brushes must be adopted if the machine is to deliver its rated output.

Sparking could be reduced by moving the brush forward (in a generator) to the commutating axis denoted by the dotted line to the right of 0 degrees as indicated in (c), but as this would result in the coil being short-circuited, when it is cutting considerable flux, a loss of useful power would result, and the machine would not deliver its rated output.

When the brushes are moved forward in the direction of rotation, the brushes are said to have a *lead*. When they are moved counter to the direction of rotation, they are said to have a *lag*. In a generator the brushes must lead slightly for sparkless commutation, while in a motor they must lag unless the machine is fitted with interpoles, in which case the brushes are fixed at the neutral point at all times.

17.6. Commutating Poles.—The problem of brush sparking has been solved by the use of *commutating poles* which are also known as *interpoles*.

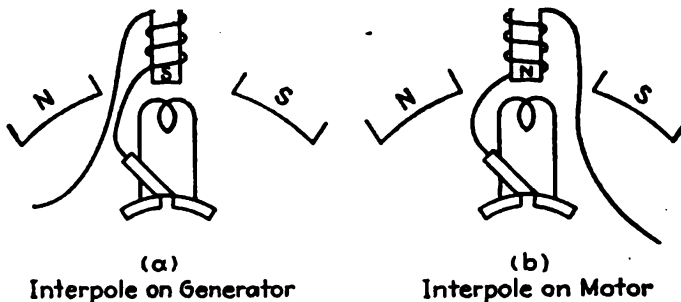


FIG. 17-10.—Interpole connections.

As shown in the preceding explanation of brush sparking, this sparking is caused by the self-induction of the armature coil in contact with the brush. In order to counteract this self-induction it is necessary quickly to reduce the current in the armature coil as it passes between poles and to cause a reversal of the current while it is yet being short-circuited by the brush so that the reversal will not come so suddenly, just at the moment when the brush is leaving the bar, and thus cause abnormal sparking. This can be accomplished by placing a small field pole between the main field poles of the machine. This commutating pole or interpole consist of a relatively few turns of heavy wire forming a coil which is connected in series with the armature, as shown in Fig. 17-10(a). It is to be noted that the polarity of the interpole of a generator is that of the next field pole, in the direction of rotation; while in a motor the

polarity of the interpole is that of the field pole just passed, in the direction of rotation as shown in (b). The reason for this difference will be clear when the theory of motor rotation is understood; this will be explained in Sec. 17.16 on motor principles.

The advantages of the commutating poles are as follows: Without interpoles the brushes must be shifted to the neutral point, which varies with the load; with interpoles the brushes are always at the neutral point owing to the action of the interpoles in counteracting the self-induction of the armature; without interpoles the momentary overloads are limited to about 50 per cent of the rated capacity of the machine, but with interpoles these overloads may range as high as 200, 300, or even 400 per cent without damage to the machine owing to the absence of sparking; motors without interpoles are limited in their speed range to 40 or 50 per cent above normal; motors with interpoles may have their speed increased four or five times normal without harm.

In addition to the points already mentioned, interpoles neutralize armature reaction, and the losses consequent thereto, and raise the overall efficiency of the machine to a considerable and important degree.

17.7. Compensating-field Windings.—As the size of the direct-current motor or generator is increased so is the armature reaction and the consequent field distortion. In order to reduce this field distortion, a few turns of heavy conductor are wound around the face of each field pole to provide a m.m.f. equal but opposite to that produced by the armature. These *compensating turns* on each pole form a *compensating coil*. The compensating coils on all the field poles are connected in series to form the *compensating-field winding*. This compensating-field winding is then connected in series with the armature, as in this position the compensating field is directly affected by the load on the machine. When the load is light, the armature reaction is light. The armature reaction being light, it requires only a small compensating field to oppose its distorting effect on the main field. This is automatically taken care of by the lighter field produced by the light current flowing through the compensating field which is in series with the armature drawing a small current on a light load. Likewise, when the load is increased, so is the compensating field.

Commutating poles as well as compensating fields may be used on the same machine, but when compensating fields are used, the ampere turns on the commutating poles may be reduced as much as 70 or 80 per cent compared with the turns necessary without the compensating fields.

It should be understood, however, that compensating fields do not aid the reversal of the current in the short-circuited armature coil thereby aiding commutation; but rather the aid to commutation lent by the compensating fields comes through their opposition to armature reaction and the consequent reduction in field distortion thereby affected.

17.8. Double-commutator Generators.—The weakest point in a high-voltage direct-current generator is the armature insulation. When an output of over 1,000 volts is generated, it becomes extremely difficult to

insulate the armature windings and commutator and to protect against high-voltage breakdown. In spite of this difficulty, generators are commercially available to supply as high as 12,000 volts. On these high-voltage generators it is the practice to divide the output-voltage strain between two commutators, allowing each commutator to take half the strain. To get full voltage, the outputs from the two commutators are connected in series. Spare armatures are usually available wherever these high-voltage machines are used so that, if an armature does break down, it may be quickly replaced.

17.9. The drum armature is so called because the windings are wound over the outside of the armature core as over the outside of a drum, all of the wire lying on the surface of the core (see Fig. 17-11).

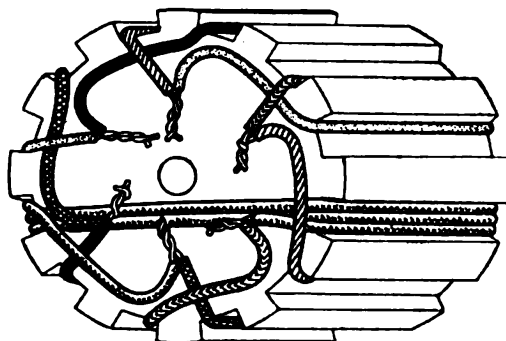


FIG. 17-11.—Skeleton view of drum armature.

The idea of the drum winding is that the two conductors of each loop (remember, a practical armature is similar theoretically to the simple armature shown in Fig. 17-5, only it has more than one loop) shall lie under adjacent unlike poles. Study this idea, and the construction of armatures will become simple.

Now let us assume, for example, that an armature has 100 loops and they are connected in series. Electrically this armature is equivalent to a number of cells in series as shown in Fig. 17-12(a). It was shown in our previous study of the revolving loop that conductors lying under unlike

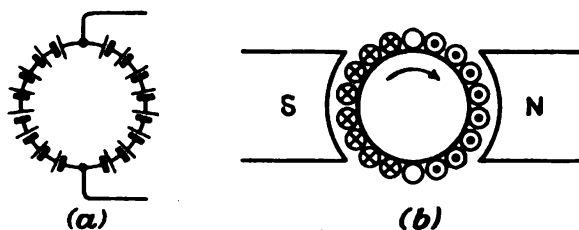


FIG. 17-12.—Armature equivalents.

poles have unlike polarities. Therefore, the conductors on an armature with many loops would have polarities as indicated on the end views of the conductors, Fig. 17-12(b). In the conductors marked with a cross, the current is flowing away from the reader; in those marked with a dot, toward the reader. The external appearance of most direct-current armatures is the same, but there are two distinct types of drum windings. These are the *lap* winding and the *wave* winding. These are shown diagrammatically in Fig. 17-13(a) and (b). A close study and tracing out of the electrical path in these armatures will make the wave and lap types of windings clear.

In low-power machines each winding element consists of more than one loop; in fact, it consists of several turns which taken together are called an armature coil. All of the armature coils in an armature are alike and are interchangeable so that a damaged coil may be removed

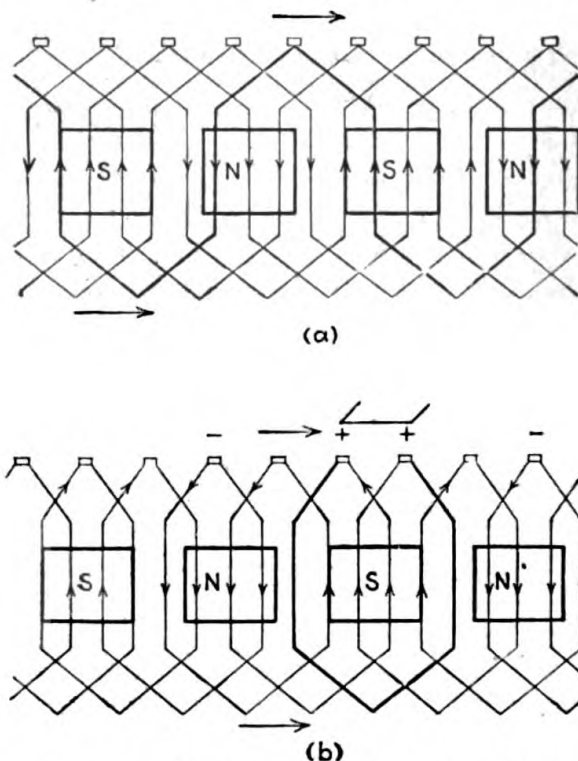


FIG. 17-13.—Armature windings: (a) wave winding; (b) lap winding.

and replaced. Each turn that goes to make up an armature coil is carefully insulated with mica and cotton or linen tape. They are then fastened together into a coil or *form* by wrapping the coil in mica and a few layers of insulating tape, the whole coil then being dipped into a moisture-proof varnish or treated by a vacuum impregnation.

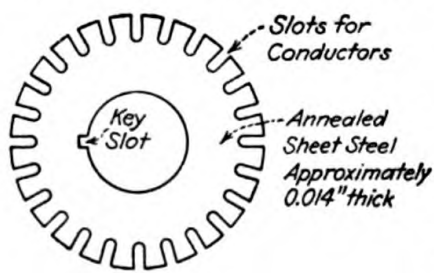


FIG. 17-14.—Steel armature-core punching.

around the perimeter of the punching form the slots in which the armature conductors are placed.

From the design standpoint, it is necessary to build generators for radio service with as large a number of armature slots as possible, to decrease the amount of slot ripple and increase its frequency, and also

17.10. Armature Cores.—The core for the modern drum armature is made up of annealed steel punchings shaped as shown in Fig. 17-14. These punchings are placed one on top of another to form a cylinder of laminated sheet steel. A key slot is provided in the center hole to prevent rotation after the punchings are assembled on the axle. The indentations

to furnish as large a number of commutator bars as possible, in order to keep down the voltage between the bars and thus reduce the possibility of sparking as well as increase the frequency of the commutator ripple. It is easier to filter a ripple when its frequency is high; hence the desire to increase ripple frequency.

17.11. Field Excitation. *a. Requirements.*—In our study of the alternator we saw that, in order to produce a field flux of sufficient density to make practical generation of e.m.f. possible, it is necessary that the field magnets be excited. It was also shown that with alternators it is necessary to separately excite the machine. It is, conversely, the general practice to make direct-current generators self-excited. An exception to this rule is a direct-current generator designed for storage-

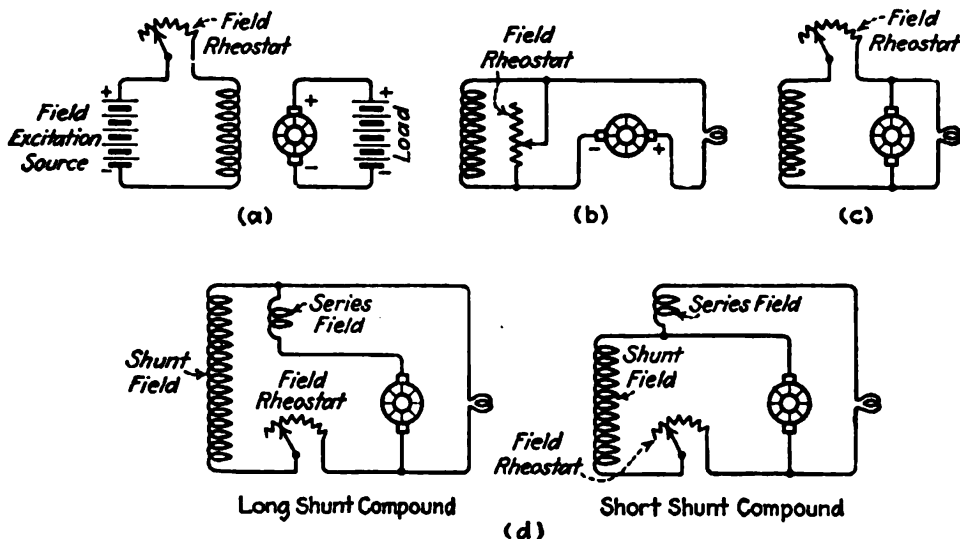


FIG. 17-15.—Methods of field excitation: (a) separately excited; (b) series excitation; (c) shunt excitation; (d) methods of compound excitation.

battery charging purposes, or for electroplating work, in both of which instances the machine is generally separately excited.

An elementary diagram of a *separately excited* machine is shown in Fig. 17-15(a). The load on this machine is a storage battery which is being charged. The field-excitation current may be a storage battery as shown, or any other source of direct current. Notice that the armature is drawn showing only the commutator. This is the conventional method of showing a direct-current machine.

b. Series excitation is shown in Fig. 17-15(b). When the armature of this machine starts to turn over, it cuts the lines of force set up by the residual magnetism of the field poles which induces an e.m.f. in the armature. If now the armature continues to rotate and the circuit is closed, a current will flow. This current flows out of the armature, through the field and load, and back to the armature. The current in the armature circuit, which is compelled to flow through the field circuit, excites the field, and the machine is said to be self-excited. Because the entire current generated by the series machine must pass through the field winding, this winding must be of a

heavy wire of sufficient current-carrying capacity to handle the load without undue heating.

c. *Shunt excitation* is shown in Fig. 17-15(c). As soon as the armature starts to rotate, the residual field induces an e.m.f. in the armature which tends to increase the field flux. As the rotation continues, the e.m.f. in the armature increases and, as the field is connected across or in *shunt* to the armature, a current will flow. If a load is connected to the armature as shown in the figure, the armature current will divide itself, part flowing in the field, and part to the load, circuits. The field winding of a shunt machine may consist of several thousand turns of insulated wire, the exact number of turns depending on the size of the machine. This field winding, therefore, has a high resistance and allows only a small fraction of the armature current (3 to 5 per cent) to flow through the field; the rest flows through the load circuit. It is evident that the shunt machine is self-excited by virtue of its field being connected across the armature. Because of the relatively small current flowing through the field of a shunt machine, the shunt windings are of a small-size wire compared with series-field windings.

d. *Compound excitation* is a combination of series and shunt excitation as will be seen by referring to the diagrams in Fig. 17-15(d). It will be noted that there are two methods of connecting the shunt field, that is, it may or may not be shunted around the series field. If the shunt field is connected around the series field it is called a *long shunt*; if not, it is called a *short shunt*. Usually, when a compound-wound machine is referred to, a long-shunt machine is meant unless specifically stated otherwise.

In a compound machine the series field consists of relatively few turns of heavy wire, while the shunt field consists of many turns of fine wire. All field windings are of insulated wire, of course.

Compound generators are always *cumulatively wound*, that is, the *series and shunt fields aid each other* in making the total flux of greater density than that of either field alone.

17.12. Brushes.—The brushes of a direct-current machine make contact with the commutator. Brushes are made in two types, namely, *copper-leaf* brushes and *carbon* brushes. The former have a current-carrying capacity of 150 amp. per square inch and are, therefore, used on heavy-duty machines. Carbon brushes can carry 35 amp. per square inch and are satisfactory for small machines.

A multipolar machine may have only one pair of brushes, or more than one pair might be used. The number of brushes used never exceeds the number of poles on the machine. The reason for more than one pair of brushes on a machine is to divide the load and reduce commutator sparking, heating, and other excessive wear which tend to ruin the commutator. On a two-wire system, if more than one pair of brushes is used on the generator, all of the positive brushes are connected to one terminal of the machine, and all of the negative brushes are connected to the other terminal.

17.13. Voltage Control on Direct-current Generators.—The terminal voltage of separately excited, shunt, and compound generators is controlled by connecting a variable resistance called a *field rheostat* in series with the field coils, as shown in Fig. 17-15. The terminal voltage of a *series* machine may be controlled by shunting a variable resistance of

high current-carrying capacity around the series field thereby controlling the amount of current flowing through the field and consequently affecting its excitation.

17.14. Uses of Various Types of Generators.—Whether a generator should be separately, series, shunt, or compound excited depends entirely on the service demanded. In addition to the characteristics pointed out before, the separately excited generator will show a variation in terminal voltage almost in direct proportion to the speed variation; that is, the voltage rises in a straight-line characteristic as the speed is increased, and vice versa. The effect of varying the speed of shunt and compound generators is greater than in the separately excited machine. In other words, this characteristic is expressed as being steeper. This means that the voltage rises more quickly in shunt and compound machines as speed is increased and also falls more quickly when speed is reduced than does the voltage of the separately excited machine.

Where the load does not change much, a simple shunt machine is satisfactory. The shunt generator, therefore, is used extensively for battery-charging purposes and as an exciter for alternators. On the other hand, where there are sudden and large changes in load to take care of, the compound-wound machine is more suitable.

17.15. Regulation.—When a load is applied to a generator there is a drop in the output voltage from a *no-load* (*nl*) value to a *full-load* (*fl*) value. This change in voltage under these conditions is called the *inherent* regulation of the machine. If expressed as a percentage of the rated *full-load* voltage by applying the following equation,

$$\text{Regulation percentage} = \frac{E_{nl} - E_{fl}}{E_{fl}} \times 100 \quad (1)$$

When considering an alternating-current circuit, regulation as expressed above is dependent upon the power factor of the circuit. A lagging current causes a greater reduction in voltage when the load is applied than the same current would cause were it in phase with the voltage. This, of course, affects regulation adversely. On the other hand, a leading current, such as is caused by a capacitive load, improves the regulation, causing a higher terminal voltage with full load than with no load.

The term *regulation* meaning inherent regulation in per cent is ordinarily applied to generators, motors, transformer, rectifiers, filters, and rectifier-filter combinations. Voltage regulation is usually meant in all references except to that of the motor when speed regulation is the factor of interest. The equation here given lends itself to application to any of these devices or factors. For example, when figuring the regulation of a motor generator, either speed, frequency, or voltage regulation could be computed by letting the subscript *nl* stand for no-load condi-

tions, and the subscript *fl* represent full-load conditions when adjoined to the appropriate letter to represent speed (*S*), voltage (*E* or *V*), or frequency (*f*). When figuring transformer regulation, only voltage is involved.

The speed of a generator affects its regulation, owing to the induced e.m.f. being dependent upon the rate of cutting of the lines of force by the armature conductors, assuming that the field excitation remains fixed. In other words, as the speed is varied, the terminal voltage is varied proportionately. Best regulation is obtained when the machine is run at its normal speed.

Full load in the above equation as represented by the subscript *fl* means the full load to which the regulation applies. For example, the regulation of a motor generator or rectifier may be 25 per cent at half load, or it may be 35 per cent at maximum load. However, if the apparatus is used on a transmitter which draws only one-half the power for which the apparatus is designed, full load is only 50 per cent of the maximum rated load that the apparatus is capable of handling. Therefore, for our equation the full-load factor is the load which is on the power supply when the key is pressed. If the same power supply, be it a generator or rectifier, is used on another transmitter which draws the maximum rated load of the device, then a new value of regulation percentage would be found. Hence, when a regulation percentage is stated or referred to, it is assumed to apply to the maximum load on the apparatus, unless it is specifically stated otherwise.

II. MOTORS

An electric motor is a device for converting electrical energy into mechanical energy. In this respect its function is just the reverse of that of the generator. A motor will produce mechanical energy only when an external source of electrical energy is forced through its windings by an impressed voltage.

17.16. The construction principles of the direct-current motor are the same as those of the direct-current generator, and the motor may, in nearly every instance, be used as a generator. The basic principles on which the motor operates are explained as follows:

When a wire carrying no current lies at rest in a parallel magnetic field, the magnetic lines of force pass from the north to the south pole undisturbed, as shown in Fig. 17-8(a). As soon as a current flows in the wire, this condition is changed, for a field immediately surrounds the wire. The lines of force constituting this field rotate counterclockwise looking along the wire in the direction of current flow. As the conductor is in the midst of the field produced by the poles, it is evident that on one side of the wire the field around the conductor and the field between the poles of the machine will counteract one another thinning out the field, while on the opposite side of the conductor these two fields will join, being both in the same direction, strengthening the field, and forcing the conductor sideways.

When there are many armature conductors, as there are in all practical motors, the effect of the field produced by the armature conductors on the field produced by the field poles is as shown in Fig. 17-16, where the entire field is distorted, the lines being much denser on one side of the conductors than on the other. This uneven density of the field flux causes the armature to rotate.

The armature of a direct-current motor is exactly like that of a direct-current generator and may be built in accordance with any of the conventional methods of building direct-current machines as explained in Sec. 17.9.

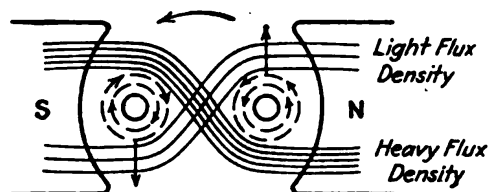


FIG. 17-16.—Field effects in motor showing how density of flux is greatest on diagonal sides of armature conductors.

Based on the fact that *actual current flow in a wire is from negative toward positive*, a rule called the *right-hand rule* has been formulated to give the relationship between current flow in the armature, direction of field flux, and direction of rotation in a revolving armature direct-current motor. This rule is stated as follows (see Fig. 17-17): *Point the forefinger*

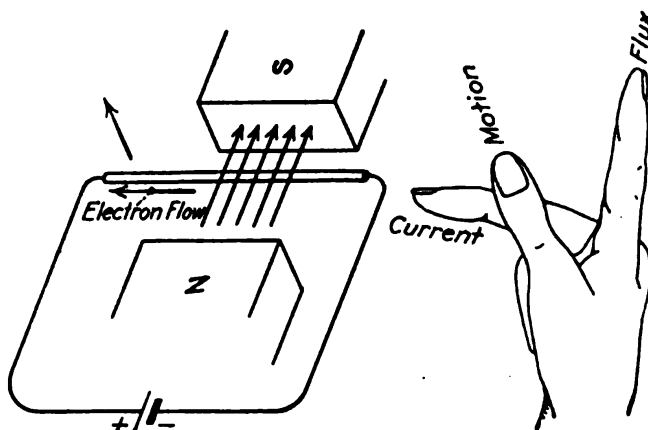


FIG. 17-17.—Right-hand rule for motors.

in the direction of the flux, the middle finger in the direction of current flow; then the thumb will point in the direction of rotation.

17.17. The function of the motor commutator on a direct-current motor is to maintain the proper direction of current flow in the armature coils in relation to the magnetic field, so that the rotative effort of all coils will be in the same direction. All direct-current motors are equipped with commutators. Commutators are also used on certain types of alternating-current motors for starting purposes.

When an external source of e.m.f. is applied to the terminals of a direct-current motor, a current is forced through the armature and field windings. The current which passes through the field windings sets up a magnetic field between the pole faces. The armature conductors lying in this magnetic field and carrying current are forced to move out, and

other conductors are carried in between the pole faces. The current flowing in the conductors just entering the magnetic field is kept in the same direction as that in the conductors leaving the field, by means of the commutator, which reverses the current in the armature coils at the instant the coil is at the neutral point between the poles. Figure 17-16 shows the attraction and repulsion between the magnetic fields and the conductors of the armature in a motor.

17.18. Counter Electromotive Force : Torque.—There are two e.m.fs. present in a motor armature: the greater is the impressed e.m.f. which is sent into the armature from an outside source; the other is an e.m.f. induced in the armature conductors when it rotates in the motor field. This last mentioned e.m.f. is called a *counter e.m.f.* because it is of opposite polarity to the impressed e.m.f. As the direct-current resistance of the armature is fixed in value by the amount and size of the armature-winding wire, and as the impressed voltage is normally fixed, the current flowing in the armature is governed by the counter e.m.f. produced by the armature rotation.

If the speed of the motor is increased, the counter e.m.f. increases, the drop across the armature decreases, and the current decreases. It is for this reason that a motor draws more current on starting than after it is up to speed; there is no counter e.m.f. in an armature which has not yet commenced to rotate.

The counter e.m.f. is always just a little less than the impressed e.m.f. in a motor.

Torque is the measure of the tendency of a body to rotate, and it may be expressed in pounds of force at a given radius. It is not necessary that there be motion in order that there be torque. As an example, suppose the emergency brake on an automobile is tightly set so that the rear wheels cannot possibly move. If power is now applied (not enough to cause the brakes to slip), a force is exerted on the wheels although there is no motion. Torque is the twisting power exerted on an object. It is easily seen that an enormous torque may be applied and not a single foot-pound of work done. Torque in an electric motor varies as the product of work done. Torque in an electric motor varies as the product of the field density (flux), times the armature current.

17.19. Types of Direct-current Motors.—Direct-current motors have their fields and armatures connected in various ways similar to the methods employed for direct-current generators. This can be seen by comparing the generator connections shown in Fig. 17-15 with the motor connections shown in Fig. 17-18. It is to be remembered that the only difference between a direct-current motor and a direct-current generator is that one is driven mechanically and sets electricity in motion, while the other is driven electrically and produces mechanical energy.

a. The Series Motor.—This type of motor, shown in Fig. 17-18(a), is used on services requiring quick acceleration with a heavy load. The load must never be taken off a series motor because, if this happens, the motor will race and tear itself to pieces. The series motor is not used in radio service and, therefore, will not be further discussed here.

b. The Shunt Motor.—The shunt motor diagram (b) is used for service in which constant speed is an important factor. This type of motor, once it has reached full speed, will maintain this speed in a very steady way, regardless of variation of the load.

In order to understand why this type of motor behaves in this way, study its connections. Assume that a current is impressed across plus and minus at the point marked D.-C. SOURCE. This will excite the field windings. As long as the impressed e.m.f. remains constant, the field strength and excitation current will remain constant. A current which is in unit proportion to this excitation current will be forced through the armature. The motor armature now commences to rotate and attains a certain speed. The armature is now producing a counter e.m.f., due to its conductors cutting the magnetic field, which, when the motor is running at no load, is very nearly equal to the impressed e.m.f.; therefore, at no load, practically no current (amperes) is flowing through the motor.

Assume that a load is suddenly thrown on the motor; it slows down slightly but not very much. As this happens the armature will cut a smaller number of lines of force per second and will produce a smaller counter e.m.f. Because of this the current (amperes) flowing through the armature increases. This increases the torque (turning effort) of the armature and the original speed of the motor is maintained. Now, if the load is taken off, the motor speeds up somewhat, the armature cuts more lines of force per second, which in turn induces in the armature a greater counter e.m.f., preventing the motor from gaining more speed. It is, of course, true that a shunt motor does vary slightly in speed, but for correctly designed machines this variation is so slight that for the purpose of theoretical explanation it may be disregarded.

c. The Compound Motor.—This type of motor has the characteristics of both the series and the shunt machine. It is employed in such services as requires a large starting torque and a constant speed under load. Because of its series field, it is able to gain speed quickly under a load; and because of its shunt field it maintains an even speed when the load is suddenly taken away or varied. These machines are designed especially for constant speed under quick changes from no load to full load. In radio-telegraph transmitters the motor is practically running light until the key is depressed, when full load is thrown upon it immediately. A circuit diagram of a long-shunt compound motor appears in diagram (c). See Sec. 17.11d on Field Excitation for an explanation of long- and short-shunt compound machines which applies to motors as well as generators.

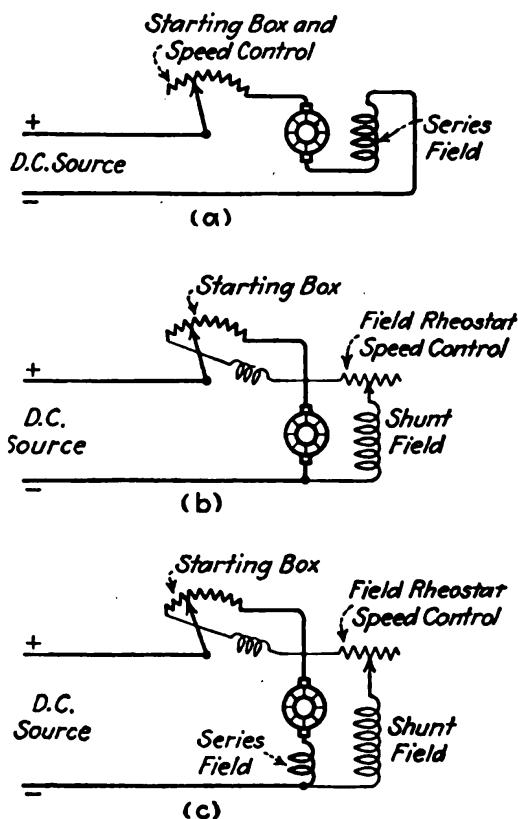


FIG. 17-18.—Types of direct-current motors.

d. *The Differentially Wound Motor.*—The differentially wound motor is a compound machine on which the series field is connected so that it is in opposition to the shunt field. This results in an automatic regulation of speed under varying loads. Remember that a weak field permits the motor to speed up. Now look at the diagram (Fig. 17-19) which shows the fields as being opposed one to the other. Imagine the motor running at normal speed. If a sudden load is thrown on the machine it will slow down just slightly. As this happens, the counter e.m.f. produced by the motor armature decreases, allowing more current to flow through the armature circuit. The series field of the differentially compounded motor is, as in all other compound machines, in series with the armature and, therefore, if the armature current is increased, the series-field current increases, which in turn increases the field of force produced by this field. But this increase in field density, instead of augmenting the field of the whole machine, bucks the shunt field (it is connected in opposition), and the resultant is a weaker field which allows the machine to increase its speed.

When the load is decreased, the current in the armature is decreased, and the series or opposition field, as it might be called, is also decreased, which allows the shunt field

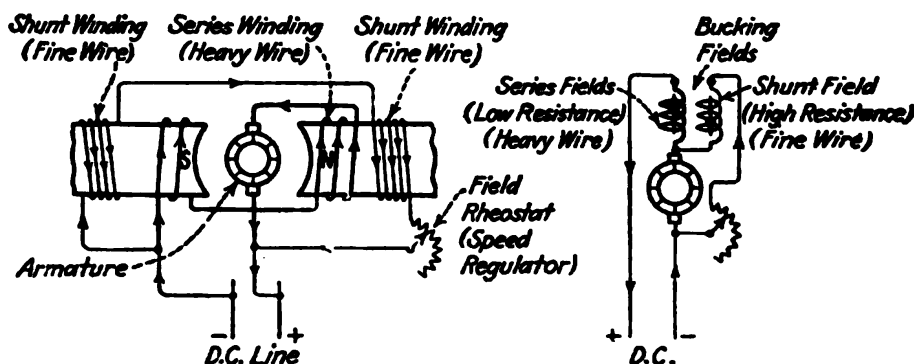


FIG. 17-19.—Differentially wound compound motor.

to exert its full influence to produce a strong field and thereby prevents the armature from turning too rapidly.

It is seen, therefore, that the series field of a differentially compounded motor serves as a very good speed regulator. This type of motor is used to a considerable extent with radio equipments and is sometimes called a *flat-compounded motor*.

e. *The Interpole Motor.*—The construction of the interpole motor is identical with that of the interpole generator described in Sec. 17.6. The function of the interpole is there explained with the aid of diagrams.

f. *Universal Alternating- and Direct-current Motors.*—If the terminal connections to a series motor [Fig. 17-18(a)] are reversed, the direction of rotation of the machine will still be the same because the direction of rotation depends upon the relative direction between field and armature currents. It is easily seen that as long as the connection of the armature to the field has not been disturbed a reversal of terminal polarity will not affect direction of rotation. Such being true, an alternating current may be applied to the terminals of any series motor and the motor will run satisfactorily. The only difference between a series motor designed for direct-current operation and one designed for alternating-current operation is that allowances must be made in core design for eddy currents set up during alternating-current operation. Eddy currents are, of course, not a problem in direct-current machines. Many small motors, especially those designed for household uses, are series machines designed for alternating- or direct-current operation.

Note on Direction of Rotation: A series motor will run in the opposite direction to what the same machine would run when used as a generator for given connections and relative direction of current flow in the circuits.

A shunt machine runs in the same direction whether used as a motor or a generator for given current direction and circuit connections.

17.20. Alternating-current Motors. *a. The Synchronous Motor.*—The synchronous motor is in effect an alternator run as a motor. The rotor field is supplied with direct current and the stator with alternating current; if the machine is gotten up to synchronous speed, it will continue to rotate and is then a synchronous motor. The synchronous motor has the advantage of running at an absolutely constant speed or

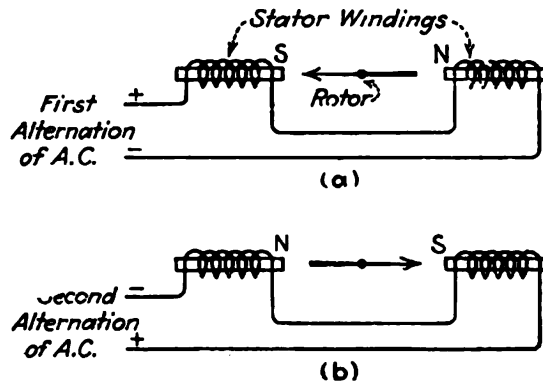


FIG. 17-20.—Principle of single-phase induction motor.

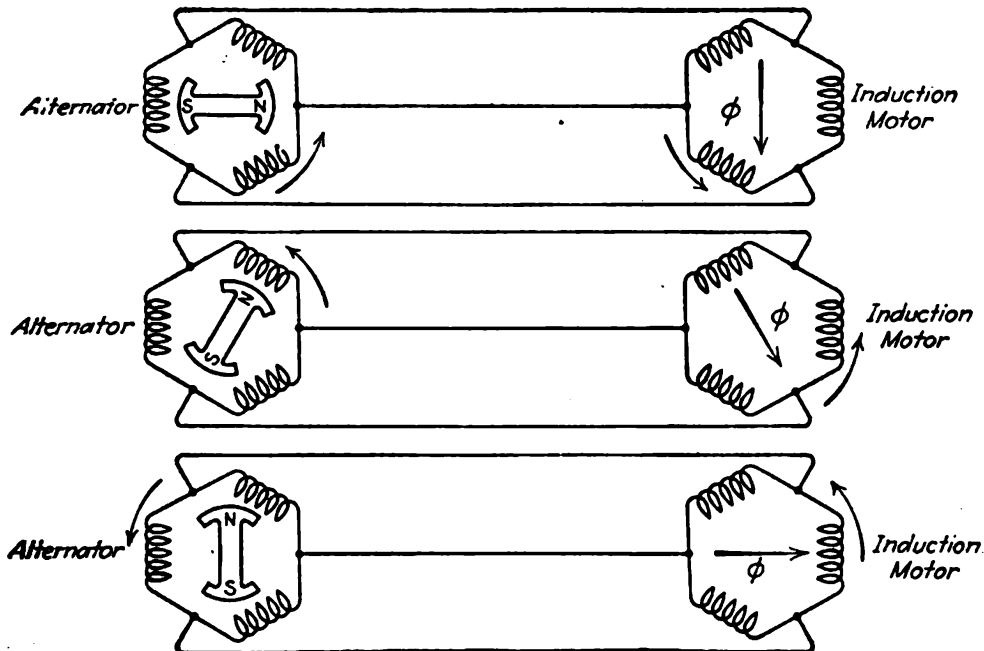


FIG. 17-21.—Principle of three-phase induction motor.

not running at all. If the load becomes too great, the motor simply falls out of phase and stops. It will burn up unless disconnected from the line immediately. Large synchronous motors are generally started by a smaller direct-current motor, attached to the same shaft, which becomes the exciter for the fields after the motor is up to speed. The circuit of a synchronous motor is identical to Fig. 17-2.

When operating with an overexcited rotor field, the synchronous motor draws a leading current from the line and in this way may be used to offset the lagging current drawn by induction motors on the line. When so used it is called a *synchronous condenser*.

b. The Induction Motor.—The induction motor differs from the direct-current motor in that it depends for its rotation upon a rotating field, in addition to the motor action produced in the conductors of the rotating element. A fundamental idea of how this rotating field is produced may be had by studying Figs. 17-20 and 17-21. Figure 17-20 shows the idea applied to the single-phase machine. In diagram (a) the arrow points toward the left, and in (b) it points to the right, which is the condition for the first and second alternation, respectively, the field having reversed itself. If now a rotor is arranged with momentum enough to carry around a quarter-revolution while the field is reversing itself, the motor will continue to run; the motor, however, would not be self-starting.

If a three-phase induction motor is connected to a three-phase alternator, a revolving field will automatically be produced in the motor as the three phases of alternating current produced by the alternator are generated. If the arrow in the motor diagram (Fig. 17-21) indicates the rotor of the motor, it will take the relative positions shown in the three diagrams for a partial revolution of the alternator as shown. Thus the rotor of the motor will follow the alternator rotor around, showing that a revolving field has been produced.

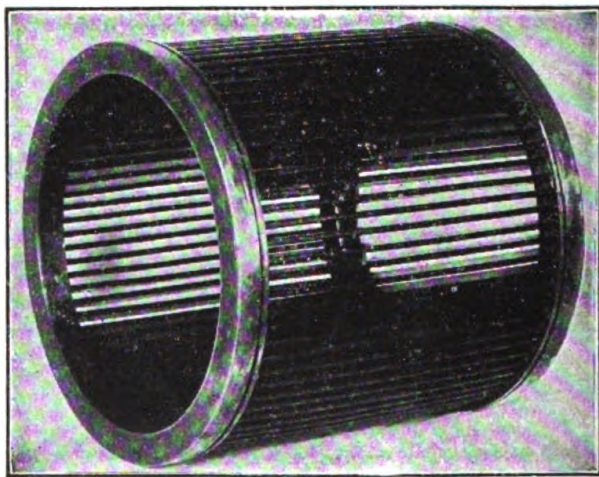


FIG. 17-22.—Squirrel-cage winding without core.

The field winding of an induction motor is called the *stator*. In small single-phase machines the stator consists of two windings, a starting winding and a running winding. The action of these two windings in causing the single-phase motor to be self-starting will be discussed farther on.

The induction motor is often likened to a transformer, the stator being the primary and the rotor the secondary. In some ways the action between the stator and rotor of the induction motor is similar to the action between the primary and secondary of the transformer and for this reason the induction motor is said to have a primary (stator) and a secondary (rotor). In the induction motor there is no electrical connection between the stator and the rotor, and in the transformer there is no electrical connection between the primary and the secondary; in this respect the induction motor and the transformer are alike.

The most commonly used secondary, or rotor, of the induction motor consists of a laminated iron core over which is fitted a *squirrel-cage winding* which is so called because of its resemblance to a squirrel cage. The squirrel-cage winding without the core is shown in Fig. 17-22 and consists of a number of conductors connected together at each end.

How the Induction Motor Works.—In the assembled motor the squirrel-cage winding is placed in a running position between the stator coils of the machine, which

coils produce a field surrounding the rotor. Whenever the conductors of the rotor are cut by the rotating field, a short-circuit current is set up in them. The reaction of this current against the rotating field produces a torque which causes the rotor to revolve. Naturally, the rotor cannot rotate so fast as the field, because, if it did, there would be no induced current and no torque to cause rotation. The speed difference between the rotor and the rotating field is referred to as the *slip speed* of the machine.

All induction motors are not squirrel-cage machines; some have *wound* rotors with the terminals of the winding coming out to slip rings similar to the rotating-armature alternator. These slip rings may be connected to resistances for controlling the motor's speed.

III. MOTOR STARTING, CONTROL, AND OPERATION

17.21. Hand-starting Boxes.—One of the most common types of hand starters is shown in Fig. 17-23. It is here shown connected to a shunt motor. The starting box is used on the larger motors, those of a size too big to be started directly from the line. The function of the starting box is to limit the armature current during starting and thus prevent

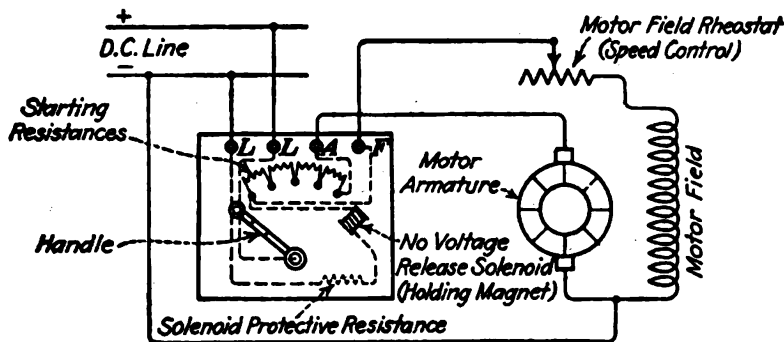


FIG. 17-23.—Hand starter, G.E. type.

the armature from burning out before it could build up the required counter e.m.f. to limit the current automatically as it does when up to speed. A study of the diagram will show that the starting box consists of a number of resistance coils which are gradually cut out of the circuit as the handle of the box is pulled over toward the right. Every hand starter has either a no-voltage-release or a no-field-release magnet. This magnet is in the field circuit, and should the current in this circuit be interrupted for any reason it loses its magnetism and the handle flies back to the off position. The handle is fitted with a spring which tends to keep it in the off position, and it will not stay over to the *full-speed* point unless the attraction of the release magnet is strong enough to hold it there.

The hand starter shown in Fig. 17-23 is the type made by the General Electric Company and has four terminal posts, indicated on the diagram and on the box by the letters *L, L, A, F*, which mean *lines, armature, and field*, respectively.

Another type of starter commonly used is made by the Cutler-Hammer Electric Manufacturing Company. This starter is fitted with

three terminal posts and is connected in the circuit, as shown in Fig. 17-24, somewhat differently from the previously described four-point box.

The handle of the starter must be pulled over quite slowly, as the motor must be started correctly, neither too slowly nor too fast. If the motor is started too quickly, the fuses will blow; or if the circuit is provided with circuit breakers, they will immediately open. The reason for this is that the motor armature, as was explained before, has a very low resistance and therefore draws a very heavy current until it attains its regular speed. There is no special rule to follow in starting a motor with a hand starter, but the speed at which the handle should be moved over can soon be determined by gaging the acceleration of the motor. Radio motor generators used on shipboard are relatively small and are usually started in 15 to 30 sec.

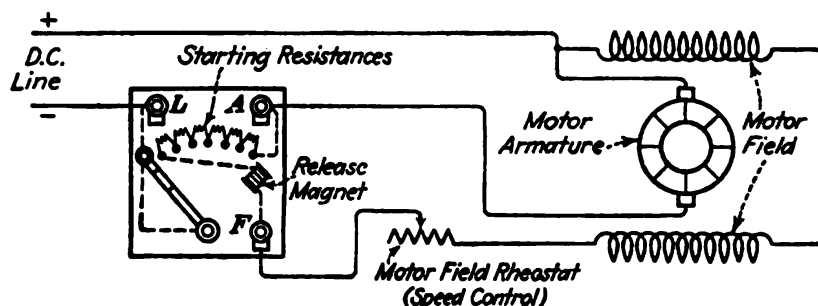


FIG. 17-24.—Hand starter, C-H type.

The resistance coils of the hand starter are meant for temporary starting duty only, and, if the current is allowed to flow through them for too long a time, it might result in burning out one of them. Pulling the starting handle over too slowly might, therefore, burn out the box. The remedy for a burned-out resistance coil is to short-circuit it until it can be repaired. If more than one resistance unit is burned out, however, it would very likely be very dangerous to use the box at all. It would be better if some emergency device, such as a water rheostat,¹ were used. Small motors of a fraction of a horsepower are generally connected directly to the line without a starter.

17.22. Automatic Starters for Direct-current Motors. a. Magnetic-relay Type (General Electric Company).—This automatic starter is shown in Fig. 17-25, which

¹ A water rheostat consists of a container, made of insulating material such as wood or fiber, filled with salt water, into which are placed three metal plates. This arrangement is placed in a shunt-motor circuit as follows: assume one side of the motor field to be connected to the negative side of the line; connect the middle plate to the positive side of the line; then connect one outside plate to the free terminal of the motor armature and the remaining plate to the free field terminal. The amount of resistance between the armature and the line and the field and the line can then be varied by moving the center plate away from the field plate, near which it should be at the start toward the armature plate. Hence, the motor starts properly with a strong field and a weak armature current.

should be referred to in connection with the following explanation of its operation. If the line switch is closed and the remote-control starting switch is open, all contactors in the automatic starter will be open and no current flows. As soon as the starting switch is closed, current flows through the solenoids of the relay, 1-LE and 2-LE, which immediately close, allowing current to flow through the armature and field of the motor. This current is limited by the two series resistors in this circuit. All heavy lines on the diagram are those carrying armature current, while the light lines carry field and control current. Current flowing through the armature also flows through relay 1-A. However, this relay is provided with an additional winding through which current is now also flowing. The polarity of the magnetism induced

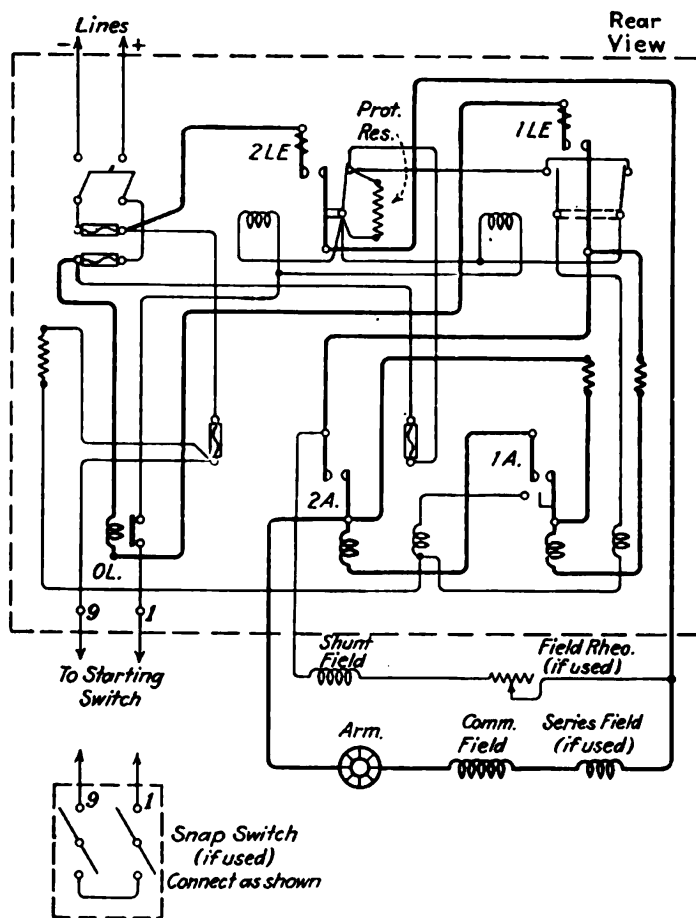


FIG. 17-25.—Magnetic-relay-type automatic starter (G.E.).

in the core by these two windings is opposite, so the resultant magnetism is very nearly zero; hence this relay does not close immediately. However, as the motor builds up speed and the back e.m.f. increases, the current through the armature becomes less. Eventually, the magnetism in this relay, due to the armature current, becomes so small that the field due to the auxiliary coil predominates and the relay closes. When the relay closes, its contacts close two other circuits, both going to the relay 2-A. The main armature current now goes through the main solenoid winding on relay 2-A, which is a low resistance, instead of going through the series resistor. Of course, there is another resistance still in the circuit. The other contact of relay 1-A closes the circuit to the auxiliary solenoid winding on relay 2-A. The current through the armature is therefore increased, since some of the series resistance has been cut out of the circuit. The operation of relay 2-A is similar to the operation

of relay 1-A, that is, this relay does not close at first, but, if the back e.m.f. of the motor builds up to a certain value, this relay (2-A) closes, and the line current goes straight into the armature without any resistance in series. Item OL is an overload relay, which stops the motor-generator set, if the armature current increases beyond a safe value. This overload relay must be reset by hand after opening. The extra contacts on relay 2-LE cut a resistance into the circuit in series with the loading solenoids of relays 2-LE and 1-LE.

When supplied to start a radio-transmitter motor generator, this automatic starter, in addition to starting and stopping the motor, also opens the field circuit

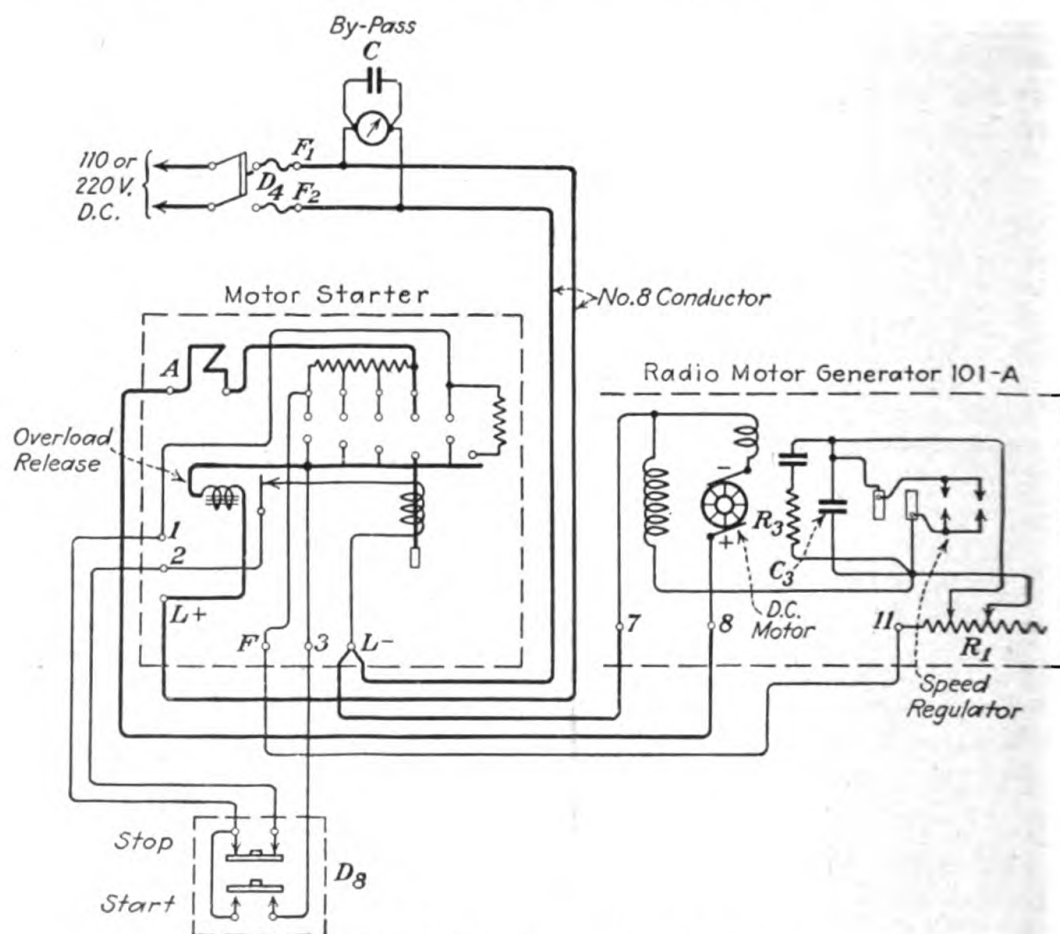


FIG. 17-26.—Dashpot-type automatic starter.

of the high-voltage generator by closing an auxiliary contactor usually located in the transmitter unit.

b. Dashpot Type.—This type of automatic starter is so called because the acceleration of the starting arm is controlled by a dashpot filled with oil. A circuit diagram of this starter as used on Mackay radio transmitters is shown in Fig. 17-26.

The dashpot-type starter is of the time-limit class of starters with four accelerating steps. It is provided with a thermal-overload relay which shuts down the motor generator in case of overload. If this relay opens, it must be reset by pressing a button on the front of the case before the motor generator can be restarted.

The motor starter is controlled from the operating table by a three-wire "start-stop" push button. This type of push button makes it necessary to restart the motor generator, by pressing the starting button, whenever the supply line is opened.

The operation of the starter may be understood by referring to the wiring diagram and studying the following explanation.

When the starting button is pressed, the solenoid of the starter is energized and the plunger starts to close five contact arms above it. Owing to an oil dashpot beneath the solenoid, the plunger cannot rise immediately and 5 to 10 sec. elapse before all the contact arms close. The first arm to make contact is the one on the right which keeps the solenoid energized when the START button is released. The arm on the left then closes and completes the supply circuit to the motor through a suitable starting resistance mounted on the starter box. The motor will then come up to speed. As the contact arms continue to close and short-circuit sections of the starting resistor, the speed of the motor will gradually increase and will reach its final value after the last contact has closed. At the end of the plunger's travel, contacts at the bottom of the right-hand arm will close, and the upper contacts on the same arm will open. This connects two small resistors in series with the solenoid, which reduces the current in the solenoid while the motor generator is running.

c. The Magnetic-saturation Automatic Starter.—The type-A series contactor, manufactured by The Electric Controller and Manufacturing Company, is magnetically operated, but it behaves quite differently from most electromagnets. For instance, it is well known that, with an ordinary solenoid, the more the current flowing through its coil, the harder any plunger in it will be pulled up. In the type-A series contactor, however, the plunger does not move when the current in the coil is larger than a certain amount, but it does lift when the current is less than this amount. As it is important to know what causes this peculiar action, the following explanation is given:

Figure 17-27*a* represents a rectangular iron frame *FF* and plunger *P*. The plunger *P* is narrower at the bottom than at the top, and the narrow part of it fits loosely in an opening at the bottom of the frame *FF*. There are two air gaps *DD* between the plunger *P* and the bottom of the frame *FF*, and one air gap *U* between plunger *P* and the top of the frame *FF*.

Next, assume that a coil is placed around the plunger *P*, as shown in diagram *b*, where the black circles represent the cross sections of the wires of the coil *CC*. The frame and the plunger are supposed to be the same in diagrams *a* and *b*. If a heavy current flows through the coil, magnetic lines will stream through the plunger *P*, across the air gap *U*, back through the frame *FF*, and through the narrow part of the plunger *P* and also across the air gaps *DD*. The reason some of the lines go through the air gap *DD* is that the narrow part of the plunger *P* is *saturated*, or, in other words, it cannot carry any more magnetic lines. These lines, therefore, are forced through the air gaps *DD* when a large current flows through the coil. The magnetic lines in the air gap *U* cause an upward pull on the plunger, but the weight of the plunger and the downward pull of the magnetic lines in the air gaps *DD* hold the plunger down.

In diagram *c*, everything is the same as in diagram *b*, except that less current flows through the coil *CC* with the result that there are not so many magnetic lines flowing through the plunger *P*, the air gap *U*, and the frame *FF*. Most of these lines can now pass through the narrow part of the plunger, but there are still a few in the air gaps *DD*. The downward pull on account of the lines passing through the air gap *DD* is now less than it was before, but this pull and the weight of the plunger are still enough to hold the plunger down.

In diagram *d* the current in the coil is still less, and, of course, the magnetic lines are less than they were in diagram *c*. Practically all of them can pass through the narrow part of the plunger *P* so that there is now very little downward pull at the air gaps *DD*. There is, however, still a heavy upward pull at the air gap *U* which is enough to lift the plunger to its new position, shown in diagram *d*.

This is exactly what happens in the operation of this starter.

Diagram *e* is a cross section of the type-A series contactor with a coil *CC*; a magnetic frame, or case, *FF*; and a plunger *P*. The bottom of the plunger is smaller than the top, like the plunger in diagrams *a*, *b*, *c*, *d*, but it is round instead of square. The magnetic lines through the air gap *U* try to lift the plunger. When the current in the coil is larger than a certain amount, the magnetic lines in the air gap *DD* hold the plunger down. Note that the air gap *DD* of diagram *e* is nearer the top of the plunger than the air gaps *DD* of diagrams *a*, *b*, *c*, *d* but that its action is the same in each case. When the current becomes less than a certain amount, practically all of the magnetic lines pass through the small part of the plunger, and there is practically no downward pull at the air gap *DD*. The pull at the air gap *U*, however, is enough to lift the plunger, which forces the contact plate *CP* into contact with the two laminated brushes *B*. When the contact plate touches the brushes it short-circuits a part of the starting resistor.

To adjust the starter, there is a hollow plug *AP* which screws into the bottom of the case *FF*. This is called an *adjusting plug* because by screwing it in or out the length of the air gap *DD* can be varied, thereby changing the value of the current at which the contactor operates. If the air gap *DD* is very short, the plunger *P* is held down and will not rise until the current through the coil has dropped to a quite small amount. On the other hand, if the adjusting plug is screwed down, the air gap *DD* is greater, and the plunger will lift when a larger current flows through the coil. It is plain, therefore, that the current at which the plunger lifts can be adjusted by screwing the adjusting plug in or out.

The main-coil arrangement of the starter is shown in diagram *f*. In actual operation, the action of the starter is as follows:

As soon as the main line or motor switch is closed, a heavy starting current flows through the operating coils of the relay, magnetizing the stem of the plunger to saturation and producing a field across the lower gap *DD*. This field, plus the weight of the plunger, holds the plunger down against the upward pull of the field at the upper gap *U*. As the motor gains speed, it produces a counter e.m.f. in its armature which reduces the current taken from the line and, therefore, the current through the coils of the relay. This weakens the field in the relay, producing a slight weakening of the pull exerted at the upper gap *U* and quite materially reducing the pull exerted at the lower gap *DD*. Finally, the field across the lower gap is so weak that it can no longer hold the plunger down against the pull of the field at the upper gap, and the field at *U* pulls the plunger up.

The non-magnetic rod extending through the top of the frame carries a contact plate which contacts two brushes, short-circuiting the starting resistance and connecting the motor to the line directly.

If the operating coil were left in the circuit, a heavy current resulting from heavy load on the motor might produce such a strong field that the plunger might be pulled down again by the effect of the lower gap *DD*; consequently, the circuit is arranged to short-circuit the operating coil at the same time that the starting resistance is shorted, a separate coil connected directly across the line being provided to hold the plunger up. A protective resistance is arranged in the circuit of this latter coil.

Opening the switch disconnects the motor from the line but leaves the holding coil connected to the motor until after the line circuit is broken; thus, when the starter drops, no current is interrupted at the starter contact. The device makes a circuit when it trips in but does not interrupt a current when it drops; thus, it never becomes pitted or burned rough. As installed on commercial radio sets, however, this type is frequently modified as required in connection with the particular control device used on the set.

To cause the relay to trip in sooner, turn the tube to the left, withdrawing it from the shell. To trip in later, turn the tube to the right, screwing it farther into the shell.

Diagram *g* illustrates how the device may be used in any number of steps.

The iron parts of the relay are copper plated so that they will not rust. Lubrication is not necessary and, as it makes the device gummy, is not desired. Keep the exposed bright parts polished, and keep dust and dirt out of the moving parts. See that the brushes make contact at the same time and fit the contact plate squarely.

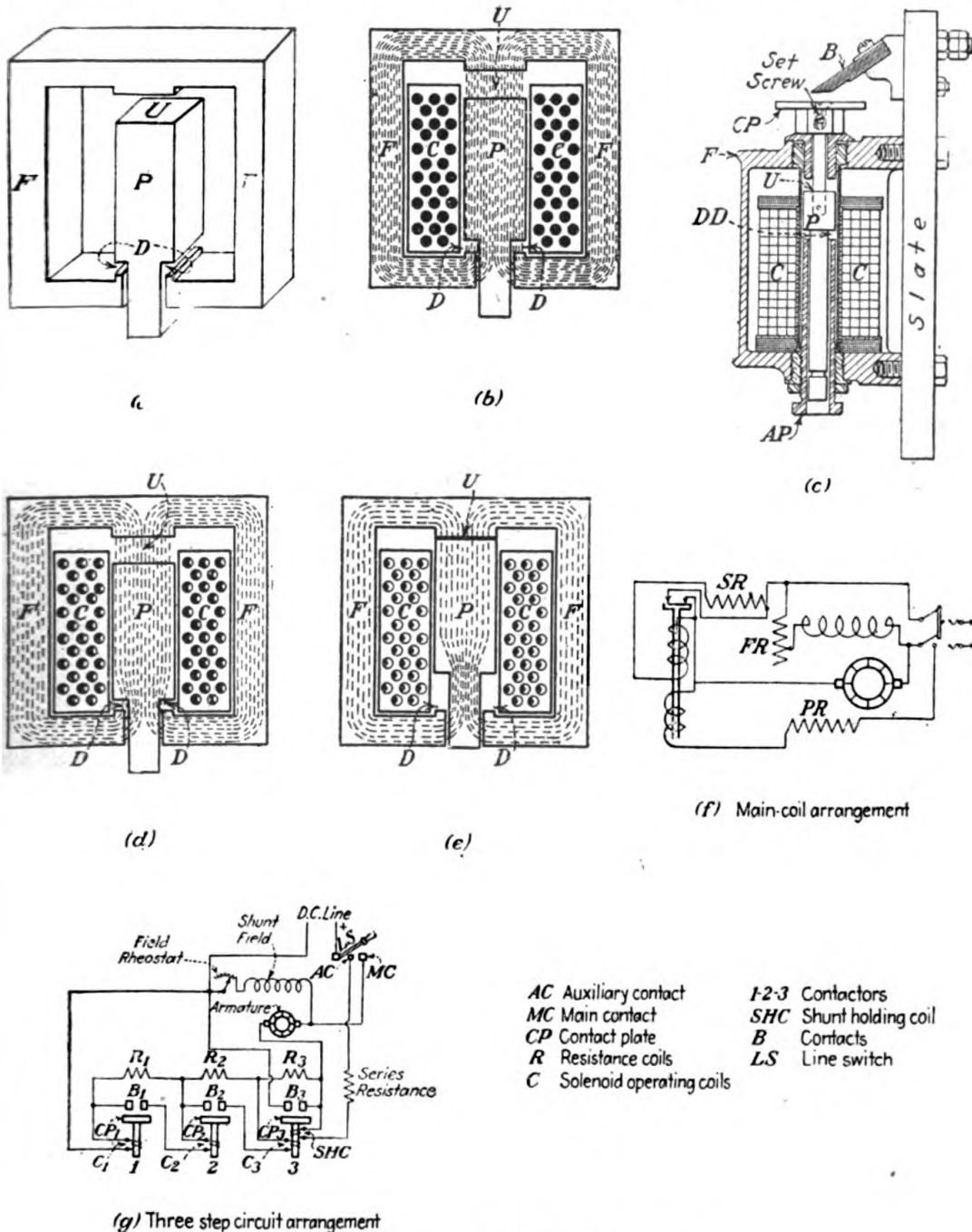


FIG. 17-27.—Magnetic saturation starter.

Unless the tube becomes loose and loses its adjustment, the above is the only care necessary.

In case it is necessary to adjust the tube, the various steps should be adjusted so that the motor is kept accelerating steadily without jerking or jumping. It is best

to screw the tubes in some distance (a couple of revolutions), start the motor, and then withdraw the tubes in order until the various steps trip in at the right times.

It will be noticed that when the last step comes in, all others drop out; thus, in stopping, when the last step is released, all are in a position to come in, in the correct order. Neither one of the plungers can come in ahead of the other as it is not connected in the circuit until the next previous has tripped in. Each one shorts its unit of the starting resistance through the operating coil of the next step.

17.23. Starting Induction Motors.—The single-phase induction motor may be started by hand, which is generally impractical, or it may be started by using a phase-splitting circuit which consists of two stator windings, a starting winding, and a running winding.

Explanation: In the phase-splitting circuit the current is sent through the stator by two paths in parallel (the starting and running windings). The inductance of one path is considerably more than the inductance of the other path which causes the current in the higher inductance path to lag behind the current in the other winding. This lag in the starting winding is 90 degrees behind that of the running winding, which causes a revolving field which starts the motor. After the motor is up to speed, a centrifugal cutout cuts the starting winding out of the circuit and the motor

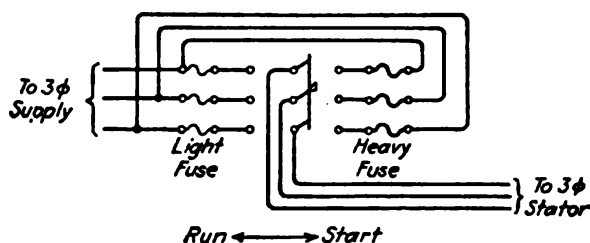


FIG. 17-28.—Starting-switch circuit for small three-phase motors.

continues to run with only the running winding in operation. The starting winding consists of relatively few turns of fine wire; the running winding consists of many more turns of heavier wire. In some motors an inductance coil in the base of the machine is connected in series with the starting winding to give it the necessary added inductance.

Small three-phase motors (squirrel cage) are generally connected directly to the line through the special starting switch, shown in Fig. 17-28. Note that in the starting position heavy fuses are provided for the heavy current drawn from the line when starting, and in the running position smaller fuses are used to give the necessary protection over long periods.

One of the most widely used starters for two- and three-phase induction motors is the *induction starter*, shown in Fig. 17-29. This type of starter utilizes the autotransformer together with a switching device which connects the stator across the autotransformer in the *starting* position and across the lines in *running* position. A tracing out of the current paths in the schematic diagram will show how this is accomplished. The long narrow rectangles shown above and below the contact points on the switch are the movable contacts of the switch.

For large machines these starters are arranged to apply the line voltage in three or more steps, while for lighter machines the voltage is applied in two steps.

A feature of this switching arrangement is that it disconnects the transformer windings from the line entirely during running position. In the starting position, in the starter shown, the fuses are not in the circuit; they are thrown in the circuit when the switch is thrown to running position. In some induction starters, heavy fuses are cut into the circuit for starting and lighter fuses for running. These starters are usually fitted with no-voltage release devices and sometimes with overload circuit breakers which take the place of fuses.

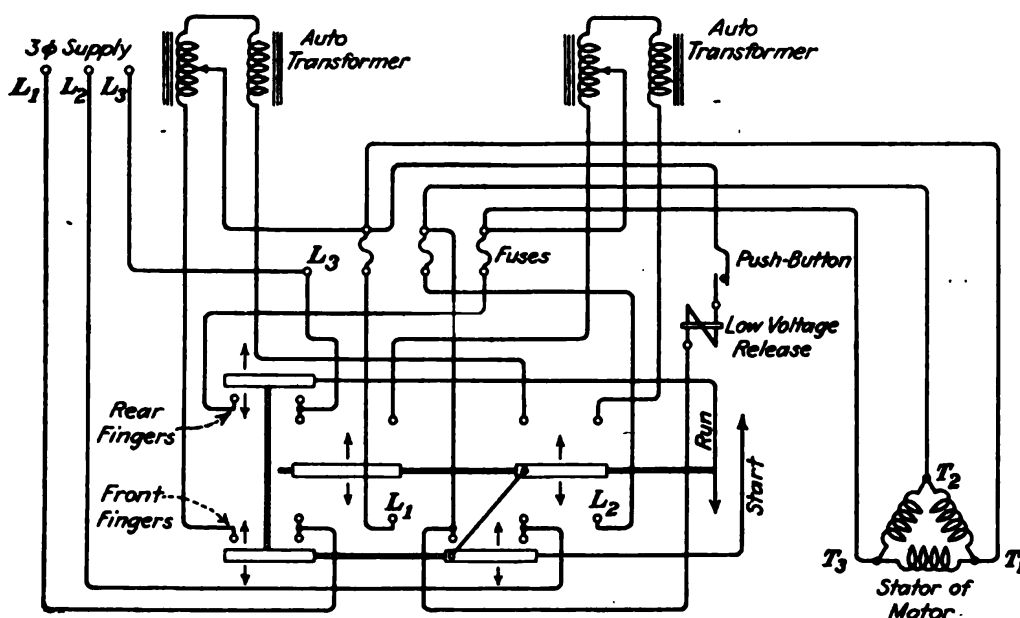


FIG. 17-29.—Induction starter for large induction motors.

Another method of starting an induction motor is to provide the machine with a commutator and brushes as a direct-current machine, except that the rotor is not connected to the supply line. This type of machine is known as the *repulsion motor*. The brushes are short-circuited, and, when the current flows in the field, a heavy current is induced in the rotor windings producing a strong starting torque. When the motor is up to speed the brushes are lifted from the commutator and the machine runs as a simple induction motor.

17.24. Manual Speed Control.—*a. The speed of direct-current motors is regulated by varying the field strength of the machine. This is done by connecting a field rheostat in the field circuit to regulate the field current as shown in the motor circuits of Fig. 17-18. Notice that in the compound machine the field rheostat is connected in the shunt-field circuit.*

Some motor field rheostats are provided with an automatic release which consists of a magnetic device, the solenoid of which is connected across the armature terminals, which short-circuits the rheostat resistance when the motor stops, thus providing a strong field when the machine is started. When the machine gets up to a predetermined speed, this automatic switch opens and puts the field rheostat in the field circuit.

Generally the resistance of the field rheostat for shunt and compound machines is about two-thirds of the field-resistance value of the machine. This allows an increase in speed of about 25 per cent. If greater speed variation is desired the resistance of the field rheostat may be very much greater than two-thirds that of the field.

b. *The speed of the single-phase induction motor* is variable over a small range and may be changed by varying the voltage applied to the motor, the torque being proportional to the square of the voltage for any given slip.

The speed of two- and three-phase induction motors varies with the load, much like the shunt motor. Under no-load conditions the speed of the motor is very nearly the speed of the field which is called the *synchronous speed*; and where the synchronous speed of an induction motor is specified, it usually means the no-load speed. The synchronous speed of two- and three-phase machines may be calculated by the following equation:

$$\text{Synchronous speed (r.p.m.)} = \frac{120 \times \text{frequency}}{\text{number of poles per phase}} \quad (2)$$

The difference between the speed of revolution of the stator field and the rotor of the induction motor is called the *slip* of the machine and is calculated by the following equation,

$$\text{Percentage of slip} = \frac{\text{synchronous speed} - \text{actual speed}}{\text{synchronous speed}} \times 100 \quad (3)$$

There are two common methods of controlling the speed of an induction motor: (1) *by varying the voltage* applied to the stator, using variable-resistance controllers, or by the more complicated compensator method by which coils are thrown in and out of the circuit thus varying the applied voltage; or (2) *by using a wound rotor* with slip rings and connecting a variable resistance between these slip rings.

17.25. The Centrifugal Speed Regulator.—This regulator which is shown attached to the motor shaft in Fig. 17-26 is capable of holding the speed of the motor constant to within 2 per cent for any variation in line voltage normally encountered on board ship. By maintaining the motor speed constant, the generator voltages can be held at constant values.

The centrifugal speed regulator consists of a pair of contacts mounted on the end of the motor shaft. One contact is rigidly attached to the shaft, while the other is

carried on a spring-supporting arm. The contacts are connected through slip rings to the ends of the fixed resistor R_1 which is in series with the field of the motor. When the motor is rotating close to rated speed, the arm vibrates so that the contacts touch and short-circuit R_1 periodically. If the motor slows down because of low line voltage, contacts either do not make contact or make contact infrequently. This causes R_1 to reduce the field current in the motor, and makes it speed up. If the motor speeds up too much, the contacts touch frequently or remain in contact. This increases the motor-field current and slows down the motor. The motor will, therefore, run at a constant speed determined by the average effect of the making and breaking of the contacts. The speed will be almost independent of small changes in line voltage or load. To eliminate excessive sparking at the contacts, the condenser C_2 is connected across the terminals of the slip rings.

17.26. Operation of Motors. *a. General Requirements.*—As the series motor is not used in radio work this discussion will be confined to shunt and compound direct-current motors and to the induction motor.

The first consideration in the operation of motors is to make sure that all connections are properly made. There are ample circuit diagrams in this book to show how all types of motors should be connected. Improper connections may easily result in serious and costly damage to the machine and associated apparatus. Check up on the starting box to see that the A terminal is connected to one armature terminal of the motor; that the F terminal on the box is connected through the field rheostat to one field terminal of the motor; and that the L terminal or terminals on the box are connected to the line. On a four-post box the remaining unconnected terminals of the field and armature are connected together and then in turn connected to the proper line terminal on the box as indicated in the wiring diagrams. Check to see that the field rheostat is connected properly.

When using a hand starter, care must be taken not to pull the handle over too fast or too slow. If it is pulled over too fast, severe sparking will occur at the brushes, the overload circuit breaker might trip, the fuses blow, or the motor itself might be damaged by an excessive current flow in the armature which has not yet had time to build up a current-reducing counter e.m.f. If it is pulled over too slowly, the resistance units in the starting box might burn out as they are designed only for temporary duty. The average motor will start in 15 to 30 sec., but a good general rule to follow is to observe the amount of sparking at the brushes to see that it is not too severe and to listen to the general acceleration hum which should be a constantly rising tone until the motor is up to full speed. Severe sparking at the commutator when starting may mean that the starting-box handle is being pulled over too fast; try pulling it over slower.

Special care must be taken not to open the circuit of a shunt field as, if this field is removed, the armature will not produce a counter e.m.f.; the motor will then race itself to pieces or burn itself out. If by accident the field circuit is opened, the motor should be immediately stopped.

To stop a motor, open the main-line switch, which will remove the power from the machine and cause it to stop.

b. The compound motor has a shunt field of many turns of fine wire and a series field of fewer turns of heavy wire. The series field should be connected in series with the armature and the remaining terminals considered as the armature terminals. The motor may then be connected to a starting box as if it were a shunt motor.

In connecting the series field in series with the armature, it must first be decided whether the motor is to be cumulatively operated or differentially operated. If cumulatively connected, the series field should be connected so that the current flows through it and the shunt field in the same direction. If differentially connected, the current must flow through the series and shunt fields in opposite directions.

c. To reverse the direction of rotation of any type of direct-current motor, it is only necessary to reverse the current flow in either the armature or field of the machine, but not in both. Practically, this may be easily done on a shunt motor by disconnecting the armature leads and reversing them, or, if the motor is fitted with a terminal block, by reversing the external wires connecting to the field posts.

On a compound motor more care is necessary when making reversing connections because of the fact that the machine has two fields, a series field and a shunt field. To reverse a compound motor, (1) reverse the armature connections alone or (2) reverse the current in both the series and shunt fields while leaving the armature-current flow as it was.

With the above requirements in mind it is a simple matter to connect a reversing switch in the motor circuit if necessary or desired.

IV. MOTOR GENERATORS AND POWER-CONTROL APPARATUS

17.27. Advantages and Disadvantages of Motor Generator.—The advantages of the motor generator over other sources of power supply lie in the easy voltage control and good regulation of output which is obtainable at full-rated voltage. The motor generator is an exceptionally rugged machine and may be located at a point remote from the transmitter and remotely controlled. It may also be operated from either alternating- or direct-current lines by simply adapting the driving motor to the power available.

The disadvantages of the motor generator may be summed up as follows: poor regulation at less than rated voltage; may require a long time to repair if breakdown occurs; may be noisy and cause vibration; requires constant attention to lubrication; and entails a high installation cost. It may be necessary to run high-voltage leads within reach of operating personnel, which may be dangerous to life.

17.28. The dynamotor combines a motor and generator in a single-frame machine which requires but two bearings. The single armature of

the machine consists of two separate windings which come out to two commutators, or two pairs of slip rings, or a commutator and slip rings, depending upon the use to which the machine is to be put. If the machine is to run on direct current and deliver alternating current, it would have a commutator on the motor end and a pair of slip rings on the generator end. If the machine is to run on direct current of one voltage and generate direct current of another voltage, it would have two commutators. It is, therefore, easy to see what a machine would need in the way of a commutator or slip rings by simply considering the conditions in the circuit.

The dynamotor has but one field winding, which serves to excite both the motor and the generator windings of the armature.

Owing to the fact that the armature reaction of the motor and generator windings are equal they balance one another out, and the machine has no armature reaction. The total losses in the machine are, therefore, less than the losses in a motor-generator set, raising the efficiency of the machine proportionately. Because the field winding does not have to overcome armature reaction, a lighter field coil may be used and the machine may, therefore, be smaller and weigh less than a motor generator.

The disadvantage of the dynamotor is that the output voltage cannot be varied without varying the input or motor excitation. It is, therefore, impossible to get the smooth regulation of voltage with a dynamotor that is possible with the motor generator.

The dynamotor is finding extensive use on aircraft and automobile installations for supplying plate power, thus eliminating the need for heavy plate batteries.

17.29. The converter, which is also known as a *rotary* converter or a *synchronous* converter, performs the same function as the dynamotor and also has the advantage of combining the functions of a motor and generator in a single-frame machine with a single armature. The converter has but one field, the same as the dynamotor, and also one armature winding, wherein it differs from the dynamotor. The armature is fitted with a commutator on one end and slip rings on the other, and the machine is used to convert alternating current to direct current or vice versa. When it is used to convert direct current to alternating current it is called an *inverted converter*.

The disadvantage of the converter is the impossibility of getting smooth voltage control because the motor and generator functions are performed by a single set of windings, which means that the input and output characteristics cannot be controlled independently.

On the other hand, where voltage control is of secondary importance both the dynamotor and converter have the advantage of costing less

than a motor generator, and also of taking up less space and of being lighter than a motor generator of similar rating.

17.30. Double-current Generators.—If a dynamotor or converter is driven by a suitable prime mover, such as gasoline engine or fan drive, two kinds of voltage can be taken from the machine. This principle is made use of on aircraft installations where such *double-current generators* are used to supply *A*, *B*, and *C* voltages to the transmitter and receiver without the use of storage batteries as the primary source of power. In order to get a constant voltage with the variation in armature speed which is likely with a fan drive, the propeller is of the self-regulating type which automatically varies the pitch of the blade according to the wind pressure. This maintains a constant speed of rotation and makes an electrical voltage regulator unnecessary. These wind-driven generators have also been fitted with differential fields, in addition to their shunt fields, which act as automatic electrical voltage regulators.

17.31. General Maintenance.—Under general operating conditions the only care required by dynamo-electric machinery is that it be kept properly lubricated and reasonably clean with well-fitting brushes and tight connections. On direct-current machines special attention must be given to the commutator to avoid sparking at the brushes with consequent harmful results. No motor or generator should be run overloaded for long periods. Most machines are designed to withstand overloads for a short period without damage to the machine.

The commutator on a direct-current machine requires more attention than any other part of the machine. Bad operation of the machine makes itself immediately apparent on the commutator as it is this part of the machine which gets the most mechanical and electrical wear. A properly functioning commutator should have a deep chocolate color, especially when carbon brushes are used, and should acquire a smooth polished surface. Roughness on the commutator may be detected by feeling the surface of the bars with the finger nails. On low-voltage machines this may be done while the machine is in operation, but on high-voltage machines the power should be entirely removed from the machine and the armature turned over by hand. Where there is any doubt as to the safety of touching the commutator, while the machine is in operation, the latter method should always be followed.

If the commutator has any roughness, it should be smoothed down with fine sandpaper. Never use emery cloth, as emery dust is metallic and particles of this dust may serve to short-circuit the commutator bars. Number 00 sandpaper is good for this purpose with a little oil applied to give a polish.

A very rough or badly grooved commutator will need to be turned down in a lathe to a new level of smoothness or, if the commutator is in very bad shape, a new commutator may have to be installed. These

operations are generally beyond the scope of the radio personnel, this work being best performed by an expert repairman.

A commutator may with wear become slightly off center which condition will cause the brushes to move up and down as the commutator revolves. To eliminate this it is necessary to turn the commutator down in a lathe until it runs on a true center. Before blaming the commutator, however, make sure that the motor or generator shaft has not been sprung so that the entire armature is off center.

17.32. Brush Troubles.—Most common brush troubles may be caused by (a) too low pressure on the brush, (b) brushes "off" electrical neutral, (c) brush not fitting properly, (d) wrong kind of brushes used.

a. Too low brush pressure will cause a slight arc to be produced between the brush and the commutator resulting in a roughening and pitting which is aggravated as the condition continues. Set the brush in the holder with enough pressure so that a good contact results when the machine is operating.

b. It should be possible to shift the brushes to a point where little or no sparking appears on full load. This is the electrical neutral and the proper operating point for the brushes. Do not attempt to shift to an electrical neutral on an interpole machine as the interpoles are designed to eliminate sparking and this should be unnecessary. On interpole machines, sparking at the brushes is caused by some other cause than the brushes being off the electrical neutral.

c. As brushes sometimes differ slightly in size, it sometimes happens that a brush does not fit into the holder properly. This may not be noticed until improper operation of the machine is traced to this cause. The remedy is obvious; the brush should be of the right dimensions to fit properly into the holder. The holder mechanism itself must keep a proper pressure on the brush during operation allowing for the wearing down of the brush as operation continues.

d. Many times, when a machine is shifted from one service to another where the load conditions are different a different type of brush will be necessary. If a trial of various types of brush available does not result in proper operation of the machine, the manufacturer should be consulted for advice on the proper brush to use.

17.33. Bearings.—Wherever there is a moving part in a machine there is friction; wherever there is friction there is wear and heat; and wherever there is wear there should be a lubricant. If a piece of steel is coated with oil, a thin film forms over the surface of the steel which cannot be removed by friction even though the steel be vigorously rubbed with a dry cloth. It is this film of oil which will wear out eventually to a point where it will be ineffective. Friction will then result between the surfaces of the rotating steel shaft and the machine bearing. It is the purpose of proper lubrication to keep the film of oil thick enough on the surfaces subject to frictional wear to prevent the steel surfaces of the shaft from being worn at all, and to keep the wear on the bearings down to a minimum.

If from improper lubrication or other causes a bearing on a machine gets unduly warm or hot, a liberal supply of cool clean oil should be applied immediately. If possible the machine should be slowed down but not stopped and the oil flushed in the bearing as much as possible.

The machine should be kept running to prevent a contraction of the bearings around the rotor shaft which is commonly referred to as *freezing* and which causes the shaft to be jammed in the bearing. Under these conditions the shaft cannot rotate until pried loose from the bearing which may be an extensive job. In cases of emergency, applications of ice held in ice-water-soaked towels may be applied to the outside of the bearing. If the machine is fitted with an adjustable bearing cap, this should be slightly loosened. Graphite mixed in with oil is beneficial if applied to a hot bearing.

In every case of overheating, the cause should be ascertained and steps taken to prevent a recurrence. All oil or grease used for lubrication purposes should, of course, be free from foreign matter and suited to the service to which it is applied.

When a machine is fitted with oil rings, these should be inspected to see that they operate properly, being loose and dipping freely into the oil well. If the machine is fitted with grease cups, give each cup a quarter-turn once each week. If a machine is fitted with ball bearings, these should be cared for according to the following directions, to apply particularly to the motor-generator set shown in Fig. 17-3, but which apply generally to all ball-bearing machines.

*The Care of Ball Bearings.*¹ *Lubrication.*—As motor generators cannot always be placed on shipboard with the shaft fore and aft, there may be times when they will be subjected to severe rolling and it is, therefore, desirable in general to use a medium grade of grease similar to No. 3 Keystone grease² which is made by the Keystone Lubricating Company of Philadelphia, Pa. A slightly lighter grease could be used in cold weather or where there would not be much rolling. Any similar good grade of grease would be satisfactory, but it must be absolutely neutral or test free from acid or alkali.

The other important requirement is that the grease must contain no fibrous material and must withstand a temperature of 100°C. or higher without any material change in its consistency when cold. Some greases, upon being heated, separate into a thin oil and a relatively viscous soapy material. This kind of a grease should not be used unless absolutely necessary. If the bearings are filled full of grease, it will be found that a portion of this will, after running for a time, work out of the ends of the bearings, leaving, however, sufficient to lubricate them properly. After operating for a month or so it is desirable to thoroughly flush out the bearings with gasoline or kerosene oil and fill with a good grease. After this, if the bearings are kept free from all dirt, grit, etc., they should not need cleaning and refilling with grease more often than every 6 months.

Cleanliness.—This is an extremely important matter with ball bearings and, therefore, all foreign material except the grease must be carefully excluded. Care must be taken that no dirt or grit of any kind is carried into the bearing

¹ Directions issued by Crocker Wheeler Company.

² Texas Oil Co.'s grease, Marfak No. 3, or equivalent, is recommended by the R.M.C.A. for their ball-bearing motor generators.

with the new grease, or otherwise, when, for any reason, the bearing caps are removed.

When the machine is not equipped with ball bearings, the oil wells and rings should be inspected at least once a month or oftener to see that they are well lubricated.

Bearings in the smaller machines are sometimes of the roller-bearing type, while in the larger machines the oil-ring type of self-oiler is commonly employed with babbitt-metal or bronze bearings.

17.34. Trouble Shooting.—Some of the most common troubles encountered in the operation of dynamo-electric machinery are open circuits and short circuits in the armature and field windings, field rheostats, starting resistances. In connection with some transmitters on ship-

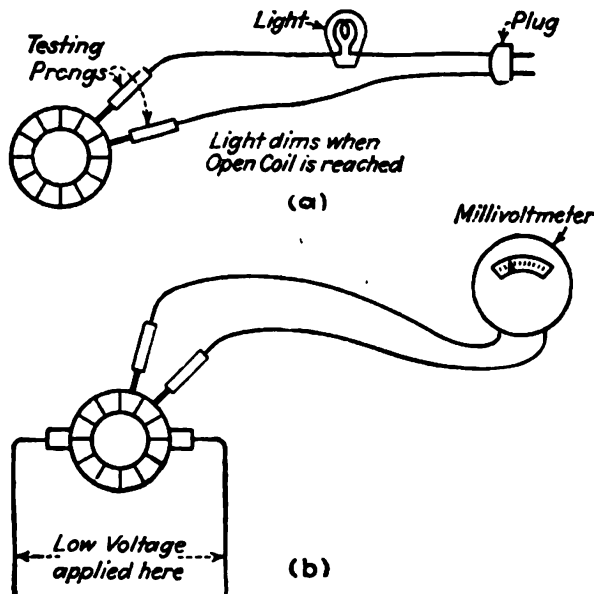


FIG. 17-30.—Method of testing armature: (a) for open circuit; (b) for short circuit.

board, a grounded protective condenser may be the cause of trouble. It is our purpose now to describe in detail tests to locate these troubles.

a. Open Circuit in Armature.—An open circuit in an armature coil will manifest itself in severe sparking at the commutator every time the open-circuited coil passes under a brush. An armature may be tested for an open coil by using a test lamp as shown in Fig. 17-30(a). When the open coil is reached, the lamp will burn dimly or it may go out, depending on the resistance of the armature winding. The machine is entirely disconnected from the line when this test is made.

Sometimes an armature coil will have a break in the wire which will only pull apart when the machine is rotating, owing to the centrifugal force then present and acting on the wires. Under these conditions the break may still be present but making electrical contact when the machine is at rest at which time it will not be apparent when the armature

is tested as shown in Fig. 17-30(a). This is known as a *flying open* circuit, and its detection is a job for an expert with ample testing equipment.

b. Short Circuit in Armature.—A short-circuited armature coil may be suspected in a motor, if, when starting the motor, the armature does not turn over until three or four points on the hand starter have been passed (or with an automatic starter, delayed starting), then runs very unsteadily at the low starting speeds, and finally heats badly in one place on the armature when the motor has been running a short time. An easy test for a short-circuited armature coil is to apply a low voltage (from a battery or through a resistance or lamp bank from the line) to the brushes, as shown in Fig. 17-30(b), and then testing by the potential-drop method across each coil using a millivolt meter as shown. When the test prongs have made connection with the short-circuited coil, the reading on the meter will drop to very nearly zero, or certainly to a much lower value than the readings across the good coils. The armature should be disconnected from the rest of the motor when making this test to prevent the current from taking any other path than through the armature coils.

c. Open or Wrong-polarity Field Coils.—To test the polarity of adjacent field coils, pass current through the windings and place two nails, one on each pole face pointing toward each other. If the polarity is right, they will attract each other; if it is wrong, they will repel one another. On some machines, where the residual magnetism alone is not enough to hold the nail to the pole face, a dead coil may be detected in this way.

Another test is to place a lighted carbon-filament lamp between the pole faces and watch the effect on the filament loops. The filament will be drawn together or forced apart depending on the direction of the flux. If a field coil is dead, no effect will be produced on the filament of the lamp.

d. Grounded Protective Condenser.—What is known as a grounded protective condenser, such as is sometimes used on transmitters on ship-board, is a broken-down condenser resulting in one plate of the condenser being electrically connected to the center post which in turn is connected to the ground. With such a punctured or grounded protective condenser one side of the line is grounded, which may result in damage to the machine if not corrected. A damaged protective condenser should be replaced, or cut out of the circuit entirely.

17.35. Protective and Control Devices. *a. Fuses* are placed in a circuit to protect the circuit and the apparatus connected to it from the damaging consequences of short circuits or other forms of overloads and to prevent the possibility of overheated electrical circuits and apparatus causing fire to material with which it is in contact or to which it is in close proximity.

Fuses are made of quick-melting alloys, the reason being that, if the circuit is overloaded, the current will rise and the consequent heat will quickly melt the fuse thereby opening the circuit and preventing damage. To prevent damage or fire from a blown fuse, the fuse strip is usually enclosed in some sort of a fireproof and insulating material. The fuse is such a common appliance that a detailed discussion of the construction of the various types will not be entered into. Suffice it to say that fuses are made to be renewable and non-renewable; the most common types are the cartridge fuse and the plug fuse.

When a fuse has blown, it should not be replaced until the cause of the blowout has been ascertained and removed. Care should be taken that the same size fuse is used in the replacement, for obvious reasons. When replacing a fuse it is safest to stand on insulating material; on shipboard avoid iron decks and do not hold on to iron bulkheads with one hand while changing the fuse with the other hand. Use insulated tools whenever possible, and be very careful not to cause other short circuits on the switchboard or panel box while making the change.

Fuses are made in various types such as the open-link fuse, consisting of fuse wire connected between two terminal blocks and used on high-power circuits in power houses and large plants; the enclosed-plug fuse, usually rated at 30 amp. or less on 125-volt circuits; the enclosed-cartridge fuse used on circuits handling any current value from 5 ma. to 600 amp. or more; and the special high-voltage fuses made in various standard ratings from 600 to 10,000 volts.

Fuses operate or "blow" by virtue of the I^2R drop present in them. Hence, a fuse has no voltage limit but has a power (watt) limit. This means that a certain critical value of power must flow through the fuse before it will blow.

b. *Switches* must be kept clean and in good condition mechanically, guarding against loose joints and faulty clips. Switches carrying a heavy current should be opened quickly to avoid blistering and burning the contact edges. If such rough spots appear, they should be removed and the surface smoothed down with a file or emery paper. Switch blades should fit snugly into the clips to insure good contact and to avoid heating. A little vaseline placed on the switch blade occasionally makes the switch work easily.

c. *The Overload Circuit Breaker.*—In power circuits where the apparatus is to be protected from overload, fuses and overload circuit breakers must be used. On all panels in commercial equipment the overload circuit breaker is usually connected in the motor armature and generator circuits. For example, if the plunger in the automatic starter should rise too quickly, or the hand starter be pulled over too quickly, the starting resistances would be rapidly cut out and a heavy current flow would flow through the armature winding. If this were not amply protected

by fuses and circuit breakers, the armature winding, due to its low resistance, would be subjected to a heavy current and the result might be a burning out of one or more of the armature coils. The overload circuit breaker in Fig. 17-31 is illustrated as being connected in series with the armature circuit to protect against excessive current flow through the armature winding.

When the handle of the overload breaker is pressed down, a laminated copper spring *A* is pressed against contacts *C*₁ and *C*₂. This allows the current to flow through the armature and the overload magnet. It is quite obvious that as soon as a current flows through *A* the overload

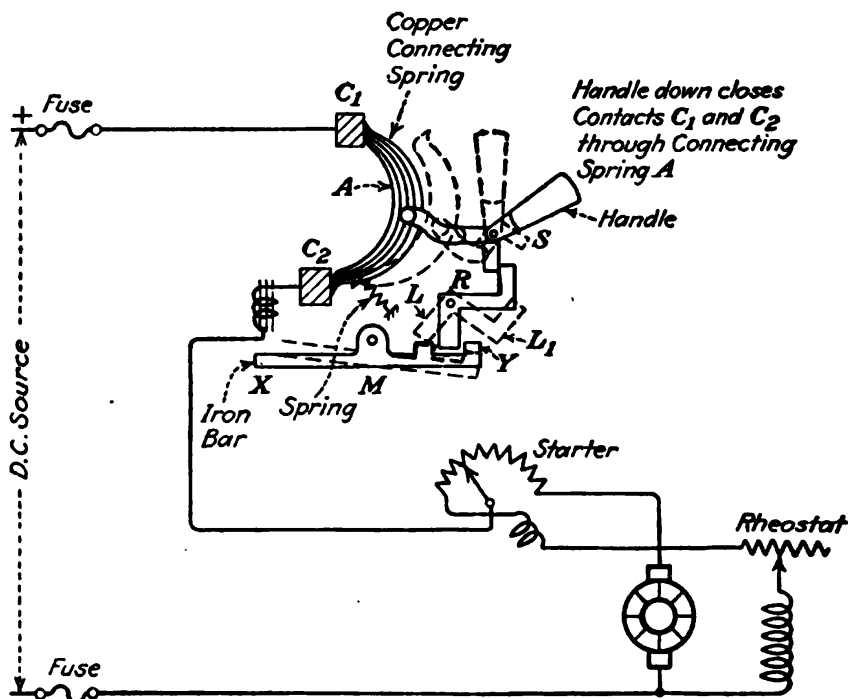


FIG. 17-31.—Details of circuit-breaker construction and circuit.

magnet is magnetized. The degree of magnetization depends upon the amount of current flowing through the armature. This magnet will attract the iron bar *M* upward toward the magnet at point *X*. This results in point *Y* dropping, which causes the release of the latch *L*.

Latch *L* then takes the position of the dotted line *L*₁, which causes a release of the handle from points *R* to *S*, incidentally releasing the copper spring *A* from the contacts *C*₁ and *C*₂, causing a break in the armature circuit.

The circuit breaker must be carefully adjusted so that it will not trip when the proper amount of current is flowing through the armature. This is accomplished by lowering the iron bar so that the distance between the bar and the magnet is increased to the proper distance. For example, if a motor, on starting, has been designed to draw 10 amp. safely, then the iron bar must be moved far enough away from the overload magnet

so that it will not break the circuit at that particular current flow. This is usually determined by experiment, although in many cases the amount of space for various amperage values is marked above the adjusting screw.

d. Vacuum Contact.—This type of contact gets its name from its construction which is shown in Fig. 17-32. Referring to this illustration it will be noted that the vacuum contact depends for its operation on the elasticity of a glass bellows *B*, because of its shape and special temper, is highly elastic. A slight movement of the stem *C* is communicated to the movable block *F*, causing it to separate from the contact block *G* which is stationary. The spring *E* causes positive con-

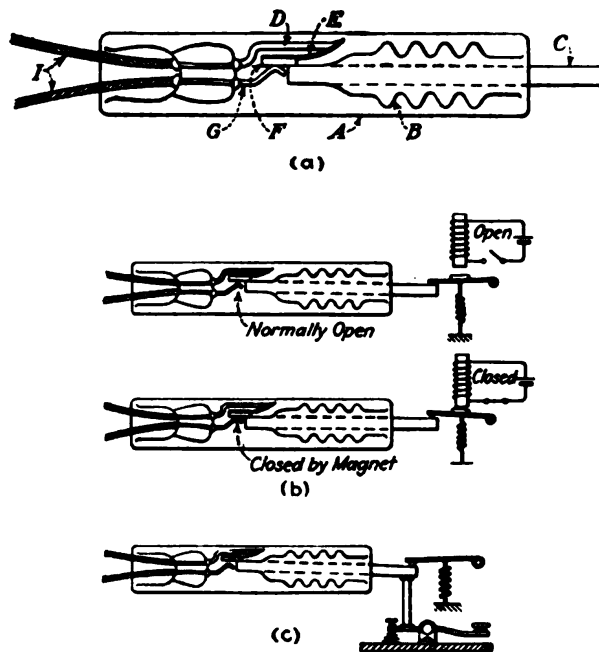


FIG. 17-32.—Vacuum contact. (Courtesy of Burgess Battery Company.)

nection between contacts when no pressure is being applied on the stem. The contacts are contained in an evacuated glass tube *A*. Connections are made through the leads *I*.

The vacuum contact is free from the drawbacks of exposed electrical contacts. There is no exposed spark and the device is therefore flame-proof. Because of their operation in a vacuum the contacts produce a minimum spark or arc and this spark or arc can be further reduced by a shunted condenser. The contact members are free from corrosion, pitting, and sticking, when the contact is properly installed, which fact assures an almost infinite life.

A very slight movement (about 0.02 in.) at the end of the stem *C* will operate the contacts. Certain makes of vacuum contacts can handle up to 1,300 watts at 220 volts as fast as 40 breaks per second, the makes and breaks being clean, positive, and reliable.

When operating at the load specified above, the vacuum contact may be shunted by a 400-volt condenser. For non-inductive loads, the condenser can be of 0.0025-mf. capacity, and for inductive loads, 0.005 mf. when operating on direct current. For alternating-current applications, a 0.01-mf. capacity is recommended.

Various methods of using the vacuum contact are also shown in the illustration (Fig. 17-32 *b* and *c*).

17.36. Generator-ripple Reduction.—Direct-current generators designed to supply plate and bias voltages to vacuum tubes must be especially designed to minimize the minute variations in their output which in the aggregate are termed the *ripple* in the generated current. The armature of the machine must be carefully designed, especially the core, which must have as many slots as possible.

As an aid in the elimination of brush sparking as a cause of ripple, it is necessary that the brushes be properly adjusted in the right position on the commutator so that the coils undergoing commutation are in the neutral zone of the field. The correct position of the brushes is usually indicated, and care should be taken to see that they are placed in the proper position. The proper position is often not exactly between the pole pieces on account of distortion of the field under load, due to armature reaction.

It is also very important that the brushes used be of suitable material. Many different materials are used, and care must be taken to select brushes which have sufficient lubricating qualities and are made of material that will not wear down the commutator while making proper contact. Only brushes furnished by the manufacturer for the particular machine in question should be used. Much damage may be done by the use of brushes which are not suitable.

In larger generators, and in circuits in which the load is variable, as in keying the transmitter, it is desirable to use distributed-field windings, with compensating-field windings, to compensate completely for the effect of the armature reaction on the field. This enables the machine to operate with perfect commutation under all conditions of load, and with sudden changes in load. Also a generator with compensating field windings may be short-circuited for short periods without damage, a strain which no other type of generator will withstand. In large machines for severe operating conditions, it is sometimes necessary to use both compensating windings and commutating poles to reduce brush sparking.

It is the practice in some of the larger broadcasting stations to float a storage-battery bank of a voltage equal to that delivered by the generator across the output of the generator (the line) to absorb variations in current output and reduce ripple. An extremely pure direct current can be obtained in this way which is especially useful on circuits supplying power to speech-input equipment where the slightest ripple is amplified millions of times by the time it is emitted from the transmitting antenna. Infor-

mation on floating batteries on the line for this purpose is contained in the following chapter, Sec. 18.14.

It is the more usual practice in most stations to use a ripple filter consisting of inductance in series and capacity in parallel with the line.

17.37. Generator-ripple filters¹ must filter out three kinds of ripple: (a) commutator ripple, (b) slot ripple, and (c) brush sparking.

a. Commutator ripple is caused by uneven voltage distribution between adjacent commutator bars, which causes a spark to take place every time a brush leaves one bar and makes contact with another. Commutator ripple F_c may be computed by the equation

$$F_c = \frac{\text{number of segments} \times \text{r.p.m.}}{60} \quad (4)$$

b. Slot ripple is caused by the interruption of the magnetic field every time a slot in the armature passes a pole piece which results in a slight surge in the field changing the voltage induced in the coils. Slot ripple F_s may be computed by the equation

$$F_s = \frac{\text{Number of slots} \times \text{r.p.m.}}{60} \quad (5)$$

c. Brush sparking is caused by an uneven contact between the commutator and the face of the brush. It cannot be predetermined by computation and can only be reduced in a given generator by proper operation of the machine and a smooth clean commutator and brushes.

Ripple filters for direct-current generators consist of inductance (L) in series with the line, and capacity (C) in shunt, or in parallel, to the line.

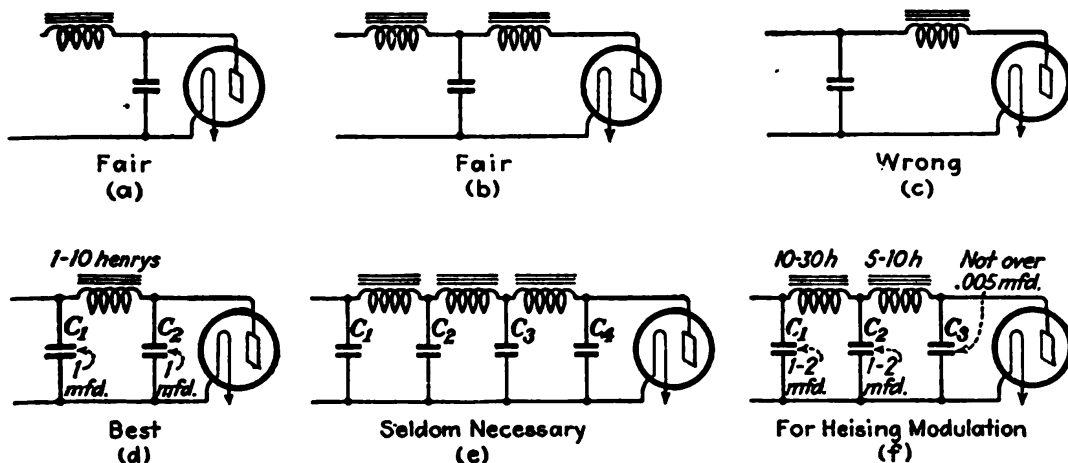


FIG. 17-33.—Generator ripple-filter circuits.

Various combinations of ripple filters are shown in Fig. 17-33. All ripple filters are low-pass filters, that is, they attenuate all frequencies above their cutoff point and pass all frequencies below this point. Their effectiveness depends, therefore, on designing them so that their resonant frequency is as low as possible. This means that the L and C in the circuit must be as high in value as practical and economic conditions permit.

¹ Condensed from "Filter Facts," a booklet from the Electric Specialty Company.

In circuit Fig. 17-33(a) the ripple voltage across the condenser is the ripple voltage across the tube which is the high-impedance load to which the condenser is connected. This may rise to several times the value of the initial voltage. The peak of this rise is reached at a frequency slightly less than resonance; beyond this point it decreases rapidly, soon becoming but a small fraction of the impressed voltage. This circuit, therefore, magnifies frequencies below its cutoff point (resonance) and greatly decreases those above this point. To be effective it must be designed with as low a cutoff point as possible which means the L and C values must be high.

In circuit (b) we have circuit (a) with an inductance added in series with the load. This is called a T filter and is not so effective as circuit (a) because it increases the cutoff frequency and allows more ripple voltage to pass.

Circuit (c) is not a good low-pass filter for generators. The voltage across the condenser will be the full ripple voltage, and the ripple voltage across the plate will vary only as the impedance of the coil in series with it varies.

The π type of filter shown in diagram (d) is one of the simplest and most economical of filters. For the generator it is ideal. Properly built it is most effective of the "smoother" types. That is, its filtering effect is not critical. It functions at all frequencies above the cutoff or resonance point. The lower this cutoff point, and the sharper and more rapid the reduction beyond this point, the better is the filter. This means that condensers and chokes as large as is practical from an economic standpoint should be used.

A general idea of the functioning of this type may be obtained by considering it as divided into two parts, A and B. Part A is the condenser C_1 across the generator. Its effect on the plate circuit is small. Its effect on the minute ripples in the generator is tremendous. Part B, the choke and C_2 , takes what little disturbance is left and reduces it further as explained for circuit (a). One or two 1-mf. condensers and a 1- to 10-henry choke make a good filter for telegraphy and telephony work. Larger condensers and chokes will, of course, increase the filtering effect.

The single-section π filter just explained should be ample for most purposes. There are some combinations such as the belt-driven generator with its surges caused by belt slap, the separately excited generator with a large ripple in the exciting current, or a generator boosted with an alternating-current supply in series with it that will need a little more elaborate filter. This may be accomplished by using a multi-section filter as shown in diagram (e). The first section reduces the disturbance a certain percentage. The next section reduces the ripple that the first section passes approximately the same percentage that the first section reduced the original ripple. The action continues with each section. The sections should be added, value for value. That is, the inside condensers will be twice the value of the outside ones, and the inductances should all be equal:

$$L_1 = L_2 = L_3; \quad C_1 = C_4; \quad C_2 = 2C_1; \quad C_3 = C_2.$$

If a π filter is used with Heising modulation, the filter should have added to it a small choke, 5 to 10 henrys, and a small condenser, not over 0.005 mf., to prevent the modulation frequencies from being short-circuited by the large filter condensers C_1 and C_2 . This circuit is shown in diagram (f).

Ripple filters, in addition to blocking out the ripple, also serve as a protective system guarding the generator against high-frequency kick-backs. Radio-frequency choke coils in the vacuum-tube plate circuits serve the same purpose by keeping radio-frequency currents out of the power supply.

CHAPTER 18

STORAGE BATTERIES¹

Storage batteries are used extensively in all classes of radio stations. They are made for both portable and stationary use, and, as far as the lead-acid type is concerned, the use for which a battery is designed determines the specific gravity of its electrolyte. Generally speaking, all lead-acid-type batteries for stationary use are of the 1.210 specific-gravity type; whereas those designed for portable use have a gravity of 1.275. The higher gravity in the portable battery may be explained by the restricted area of the plates, compared with the stationary type, and the reduction in quantity of electrolyte, which makes a stronger solution necessary. The stationary type of storage battery is used at some broadcasting stations and at high-powered radio-communication stations located ashore where an emergency power supply is desired. The portable type of battery is used on mobile stations where space and operating conditions make the installation of a stationary type impractical.

18.1. General Battery Considerations.—Storage batteries are sometimes used in connection with broadcast-studio equipment where the batteries are floated across a generator, in which position they act as a filter condenser to absorb any ripple and to provide a source of emergency power for use should the normal power supply fail. In this way the battery is always in the circuit, and in the event of a generator failure the battery is across the line and no interruption is noticed. However, its use as a ripple filter in broadcast stations is perhaps more important in practical operation than is its ability to furnish emergency power, as power failures are comparatively rare occurrences.

For marine use a 60-cell storage battery of the portable type is generally supplied. This battery provides current to operate the main radio motor generator in case of failure of the ship's generator. An emergency lighting circuit is also usually connected to this battery. Since the development of low-power vacuum-tube transmitters capable of fulfilling the requirements of the law as to transmission range, companies manufacturing radio equipment have found that a motor generator driven by a 12-volt motor is satisfactory. A transmitter of this type is described in Sec. 13.5. Under certain conditions, therefore, the emergency radio battery need only be capable of delivering 12 volts.

¹ Much of the material in this chapter pertaining to the practical operation of the lead storage battery has been taken, by permission, from instruction booklets issued by the Electric Storage Battery Company.

There are two distinct types of storage batteries, the lead-acid type and the nickel-iron-alkaline type, the latter being known as the *Edison battery*. Whenever reference is made to a storage battery, or cell, without specifying to which type it belongs, the lead-acid type is meant.

The use of the nickel-iron-alkaline battery in radio has been principally confined to installations aboard ship for use as an emergency battery to comply with the law which requires a source of emergency power for operation of the ship's radio transmitter.

I. THE LEAD-ACID BATTERY

18.2. The Lead-acid Cell.—Storage batteries produce an e.m.f. as a result of chemical action after they have been subjected to an initial charge. This action takes place between the active material of the positive and negative plates and the electrolyte, which in the lead cell is a dilute solution of sulphuric acid. The active material of the positive plates is lead dioxide,¹ (PbO_2), which is always chocolate brown in color when in its normal condition. The active material of the negative plates is commercially pure sponge lead (Pb) which is pearl gray in color when the plate is in a normal condition. If the negative plate is white, slate gray, or spotted, an abnormal condition is indicated.

The great majority of lead cells used in radio-station service in the United States are manufactured by the Electric Storage Battery Company (Exide) of Philadelphia. This company manufactures a number of general types of cells each differing in the types of positive and negative plates used. Two of these types are in common use in radio stations; they are (a) the chloride accumulator² and (b) the Exide battery. The first named is a stationary type (Fig. 18-4), while the latter is a portable battery [Fig. 18-3(b)].

18.3. Positive Plates.—There are two types of positive plates, the Planté and the Faure, the former being used in stationary and the latter in portable batteries.

a. Planté Type.—This type of plate as manufactured in the United States by Exide is known as the *Manchester positive* plate and consists of a grid of cast lead-antimony alloy which resists both electrical and mechanical strain and, therefore, retains its strength, shape, and dimensions. This grid is provided with circular openings into which are forced, by hydraulic pressure, the rosettes or buttons of soft lead which constitute the active material of the plate. The construction of the Manchester plate is clearly seen in the cell shown in Fig. 18-1. After being forced into place in the grid, the buttons are subjected to the "forming" process, whereby the active material, lead dioxide, is developed electro-chemically

¹ Lead dioxide is sometimes erroneously called lead peroxide.

² Chloride accumulator is a misnomer, there being no chloride whatever used in the lead cell.

on the transverse surfaces. The fact that there is available a supply of solid lead in the rosettes or buttons that can be converted into active material as needed accounts for the long life for which this type of plate is noted.

b. Faure Type.—This is commonly known as the *pasted* or *flat* type of plate and consists of a lattice-like grid of stiff lead alloy which supports the active material. The grid is “pasted” with an oxide of lead made into a paste of special composition which sets in drying, like cement. The plates are then subjected to an electrochemical process which converts the oxide of lead to dioxide of lead which is brown in color. This type of plate is shown in Fig. 18-2(b).

c. Exide Ironclad positive.—This is a modification of the Faure-type plate and consists of rows of hard-rubber tubes which are horizontally slotted and which contain the active material and permit free access of the electrolyte. This type of plate is visible in the cell shown in Fig. 18-3(a) and permits current drains, as high as 1,000 amp., for very short periods without injury or overheating.

18.4. Negative Plates.—While negative plates may be constructed along the lines of the Planté type, it is the practice to construct all negative plates by the Faure method utilizing two methods of grid construction, the lattice or flat type and the box type.

The lattice-type negative plate consists of a lattice-like grid on which is pasted the active material of the negative plate, sponge lead. This plate is shown in Fig. 18-2(a) and is similar in construction to the Faure-type positive plate shown in Fig. 18-2(b).

The box-type negative plate consists of a lead-antimony-alloy grid which is formed of horizontal and vertical ribs, spaced about 1 in. apart, forming pockets which are closed on both sides with perforated sheet lead, in which pockets the active material is permanently held in place. This construction is clearly shown in Fig. 18-4. The active material consists of blocks of lead oxide which are later formed into the active material of the negative plate. With this type of construction the grid is strong and rigid and is not affected by the electrolyte,

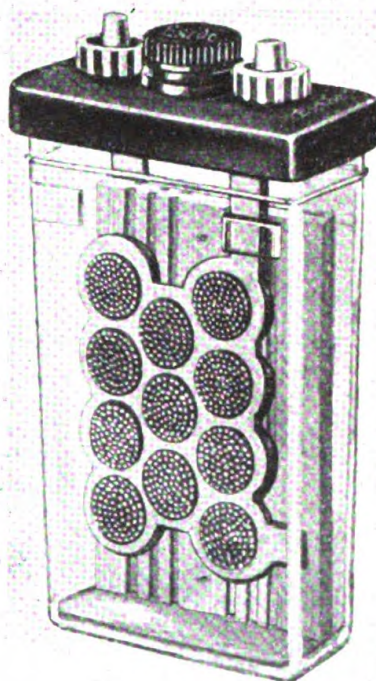


FIG. 18-1.—Two-plate lead cell showing Manchester positive plate. (Courtesy of Electric Storage Battery Company.)

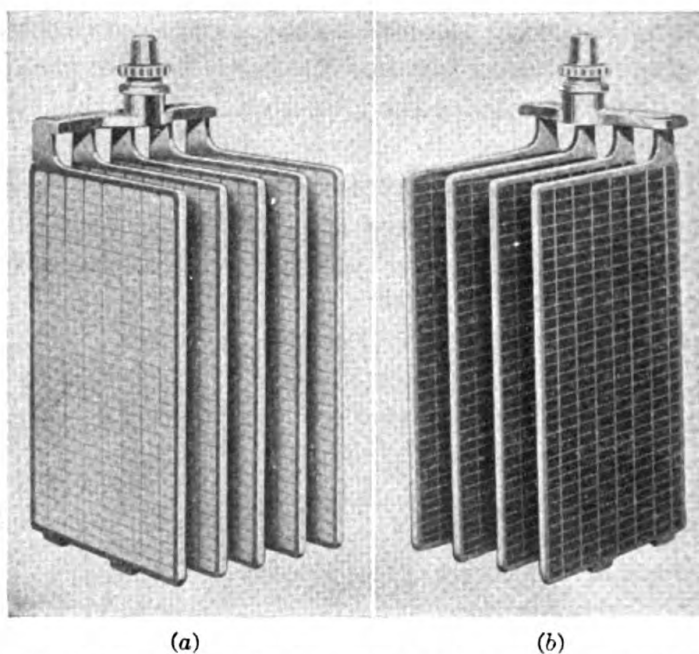


FIG. 18-2.—Constituent parts of lead-cell element: (a) negative group; (b) positive group.
(Courtesy of Electric Storage Battery Company.)

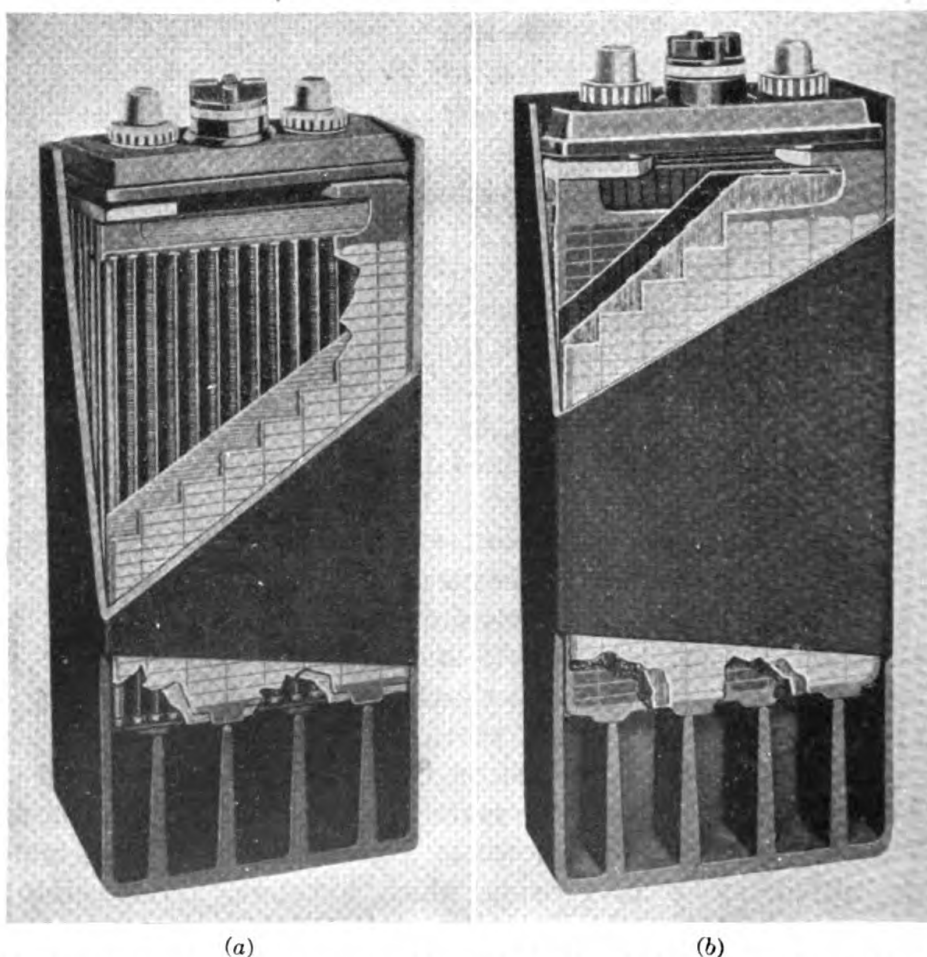


FIG. 18-3.—Types of lead batteries: (a) Ironclad Exide; (b) Exide portable. (Courtesy of Electric Storage Battery Company.)

while the active material is exceedingly porous and finely divided and retains this porosity during service.

18.5. The active material must be porous enough to allow a sufficient amount of acid to reach the active elements at all times regardless of the rate of discharge, except that this rate must always be within the rated limits of the cell.

The arrangement of the active material is dependent on whether the battery is to supply power at a high or low rate of discharge. If the rate of discharge is to be high, the material must be spread in a thin

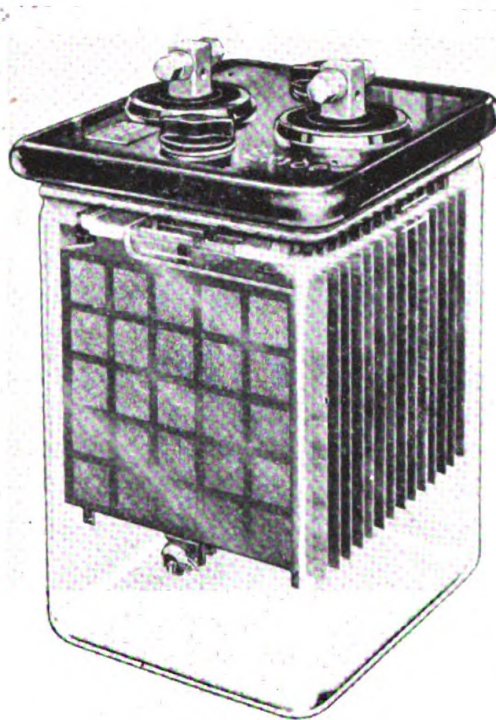


FIG. 18-4.—Stationary-type lead cell. (Courtesy of Electric Storage Battery Company.)

layer over a large area so as not to require a great depth of penetration by the acid in order to create the chemical action necessary to the production of an e.m.f. If the rate of discharge is not relatively high a greater depth of active material, measured from the surface where the electrolyte makes first contact, may be applied as ample time is then allowed for acid action and penetration.

The quantity of active material required depends upon its arrangement; if a high-capacity cell is required, the quantity of active material must be increased proportionately, and vice versa.

18.6. The electrolyte used in lead-acid batteries is made by mixing sulphuric acid (H_2SO_4) and water (H_2O). The amount of each depends upon the gravity desired, which in turn depends upon whether the stationary or portable type of battery is used, the former utilizing a

1.210 specific-gravity electrolyte, and the latter, a 1.275 gravity electrolyte. The proportion of water to acid in an electrolyte with a specific gravity of 1.210 is 4.1 by volume, while the proportion for an electrolyte having a specific gravity of 1.275 is 3.1 by volume. This assumes the use of commercially pure (93.5 per cent) sulphuric acid, having a specific gravity of 1.835.

All specific-gravity readings mentioned are at 77°F., the standard reference and average electrolyte temperature at the beginning of discharge. A plus or minus variation in the specific gravity of fully charged cells of 5 degrees in gravity is tolerated. In other words, when a cell having a specific gravity of 1.275 is spoken of, it usually means a reading ranging from 1.270 to 1.280.

The electrolyte should always be kept to the level specified for the battery, usually $\frac{1}{2}$ in. or more above the tops of the plates depending on the type of cell used. To maintain this level, never add anything but pure distilled water, or tap water which has been approved by the battery manufacturer as being satisfactory for this purpose. The reason for this is two-fold: acid does not evaporate and, therefore, a lowering of the electrolyte level indicates evaporation of water; and impure water may cause local action in the cell and plate disintegration. Electrolyte may be lost by excessive spraying or gassing on account of too high a charging rate, and for this reason filling plugs must only be removed when taking a gravity reading or adding water.

The only time when acid is added to a cell is when some of the electrolyte is spilled out and cannot be recovered. This might happen during shipment, installation, or overhauling.

Every lead cell works best with an electrolyte of a certain density or specific gravity which is determined by exhaustive tests by the manufacturer. An electrolyte of a higher specific gravity will raise the voltage of the cell and consequently its capacity, but over a period of time the life of the cell will be shortened by such overloading. It is always advisable to work a cell with the electrolyte at the specific gravity recommended by the manufacturer.

As the specific gravity of an electrolyte varies with temperature, so also does the capacity of the cell vary with temperature. Generally speaking, the capacity of a cell varies directly with change in temperature, rising as the temperature rises, and lowering as the temperature lowers. When batteries are used in very hot temperatures, better results are generally obtained by using an electrolyte of a lower specific gravity than would be required in cooler places.

Mixing Electrolyte.—Only commercially pure sulphuric acid should be used for storage-battery purposes. Do not confuse commercially pure acid with “full-strength” or “concentrated” acid; there may be a considerable difference which might work injury on the battery.

If electrolyte of the proper strength is not on hand it may be prepared from commercially pure sulphuric acid by mixing the acid with approved water. The acid may be any strength, provided it is stronger than the electrolyte desired. Special care must be taken in handling acid when it is stronger than 1.400 and extreme care when it is stronger than 1.600 to avoid personal injury.

The proportion of acid to water depends on the strength of acid used. When concentrated acid with a specific gravity of 1.835 is used, an electrolyte of 1.210 specific gravity contains approximately 4 parts water to 1 part acid by volume; whereas an electrolyte with a specific gravity of 1.275 requires not quite, but approximately, 3 parts water to 1 part acid by volume. When mixing take the following precautions:

1. Use a Pyrex glass, glass, china, earthenware, or lead vessel; never a metallic container other than lead. Rubber may be used, except when mixing acid of 1.600 gravity or stronger.

2. Slowly and carefully pour the acid into the water; not the water into the acid, as this might cause sputtering and, therefore, personal injury. Interrupt the pouring frequently, and stir thoroughly with a clean wooden paddle. Discard the paddle after using.

3. The gravity of the mixture will rise as the mixture cools. Therefore, if the mixing is completed with the temperature between 90°F. (32°C.) and 105°F. (40°C.), it should at this time read 0.005 to 0.010 specific gravity lower than desired; if temperature is between 105°F. (40°C.) and 120°F. (49°C.), it should read 0.010 to 0.015 specific gravity lower, etc.

4. Allow mixture to cool below 90°F. (32°C.) before adding it to the battery.

The temperature of the electrolyte or acid may be taken by a special thermometer supplied by the battery manufacturer which is shaped like a hydrometer and weighted at the bottom with lead granules. It is designed to float in the liquid being tested and is read like any ordinary thermometer.

18.7. Construction of Cells.—Cells are constructed in accordance with the cell type, the details of which are given in the table which follows.

Cell type	Positive plate	Negative plate	Type of service	Specific gravity
Chloride accumulator	Manchester-Planté type	Box type, Faure	Stationary land stations. Broadcasting not portable	1.210
Exide.....	Faure pasted-lattice type	Faure pasted-lattice type	Portable and stationary, usually mobile station use	1.275 for portable; 1.210 for stationary
Exide-ironclad....	Slotted tubes containing active material, Faure type	Faure pasted-lattice type	Lifeboat radio equipments	1.275

A study of the illustrations of the lead-acid batteries shown in this chapter will give the reader an excellent idea of how the cells are constructed. Referring to Fig. 18-2 it will be noted that each plate has a lug at the top. This illustration shows the Faure-type pasted plates, but cells utilizing Manchester plates have their plates arranged the same way. Regardless of the type of cell, a certain number of positive plates

are "lead burned" to an alloy strap, forming a positive *group*. The negative group is assembled in the same way, except that there is always one more negative plate than there are positive plates, so that when the plates are interlocked the outside plates are always negative. One exception to this rule is the two-plate glass-jar type shown in Fig. 18-1.

In order to insulate the positive group from the negative group there is inserted between the plates of most of the closed-jar types a grooved-wood separator, the grooved side of which goes against the positive plate and the smooth side of which goes against the negative plate. In addition to this wooden separator there is placed, in certain types of cells, a

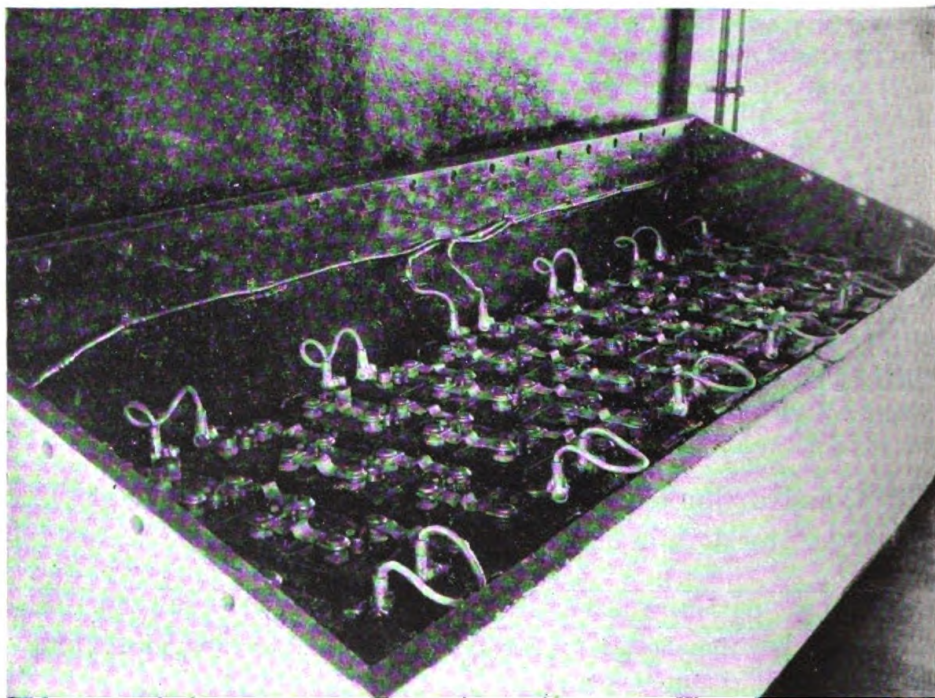


FIG. 18-5.—Lead-battery installation aboard ship. (Courtesy of Electric Storage Battery Company.)

perforated or porous rubber sheet between the wooden separator and the positive plate. The entire assembly of plates and separators is known as an *element*, and the element is inserted in a glass or rubber *jar* which contains the electrolyte. Ample space is allowed in the bottom of the jar for the accumulation of sediment, and normally this space will hold all of the sediment deposited during the life of the cell. It is, therefore, unnecessary to disassemble a modern lead-acid cell to remove sediment.

The chloride-accumulator and Exide types of cells designed for stationary service are supplied in sealed glass jars. The Exide portable-type battery is supplied in a sealed rubber-jar container. In the sealed-jar types the necessary holes are provided in the tops for the terminals, for the pouring in or taking out of the electrolyte, and for the taking of gravity readings and the addition of water.

In the old-type open-glass-jar battery the plates are suspended from the sides of the jar which rests upon a tray filled with sand. This tray is employed to catch any creepage of electrolyte which may occur and so protect the wooden racks on which the cells are mounted. The sand acts as a cushion between the glass surfaces of jar and tray and thus prevents breakage which might otherwise occur. With the sealed jar, creepage is prevented by the sealed cover, which makes sand trays unnecessary. When the open-jar-type battery is employed, a separate battery room is necessary because of the destructive acid spray present.

For stationary service the cells are mounted on wooden racks, in tiers if necessary. On shipboard, where the portable type of battery is used, the cells are mounted together in strong supporting boxes which are then called *trays of cells*. A typical shipboard installation of 60 cells is shown in Fig. 18-5. The large box which houses the installation is

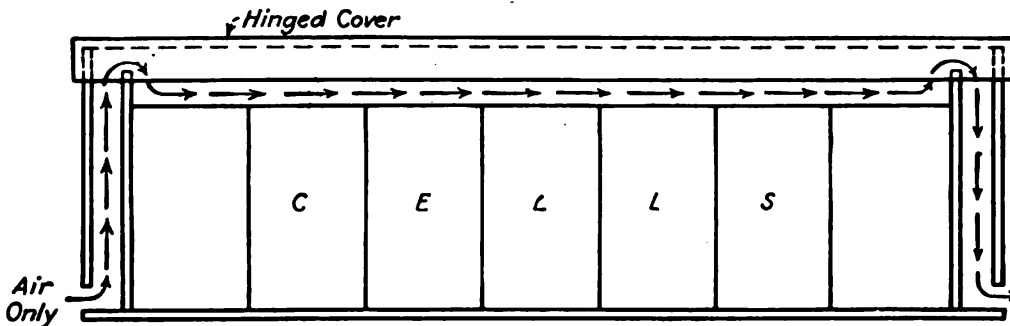


FIG. 18-6.—Plan of battery-housing box for shipboard use.

strongly built for marine use and is coated on the inside with an acid-resisting paint as are also the individual trays.

It is necessary that ventilation be provided in the battery-housing box. In the box shown in the illustration, holes are drilled around the top of the sides of the box to pass the air. This type of box should be opened during charging periods, if the weather permits, as good ventilation is then assured. A later type of box is built according to the plan shown in Fig. 18-6. Openings are provided in both ends of the box near the bottom, and the air can take the route indicated by the arrows even if the cover is down. Sea water or spray could not reach the cells housed in this type of box unless the batteries were submerged.

The purpose of the battery housing is, of course, to protect the batteries from the weather and from salt water and spray. Salt water contains chlorine which is injurious to the batteries.

18.8. Chemical Action in a Lead Cell.—The chemical action in a lead cell during one cycle of charge and discharge is shown in Fig. 18-7. Four periods are shown in which the conditions existing in the cell from the time it is fully charged until it has been completely discharged and put on charge again are represented.

Period 1 shows the charged cell with the electrolyte at the proper specific gravity, at which time all of the acid is mixed with the water and the specific gravity reading is maximum. The negative and positive plates are in their natural condition having only their active material in them. The cell is as originally assembled, except that litharge (PbO) pasted in the plates has been formed into active materials, electrolyte is present, and the cell is fully charged.

Period 2 shows the cell as it starts to discharge. The acid is leaving the electrolyte and going into and combining with the active material of the plates. As it does this it reduces the active material of the positive and negative plates to lead sulphate, decreasing the sponge lead and lead dioxide. This continues until nearly all of the acid has gone from the electrolyte into the active material of the plates. The specific gravity of the electrolyte becomes lower as the acid leaves the water and enters into chemical combination with the active materials. It is possible to measure the extent of this action by taking a reading of the specific gravity of the electrolyte and thus determine the state of charge of the lead cell. When so much of the acid has left the water that the specific gravity has dropped approximately 100 points from the

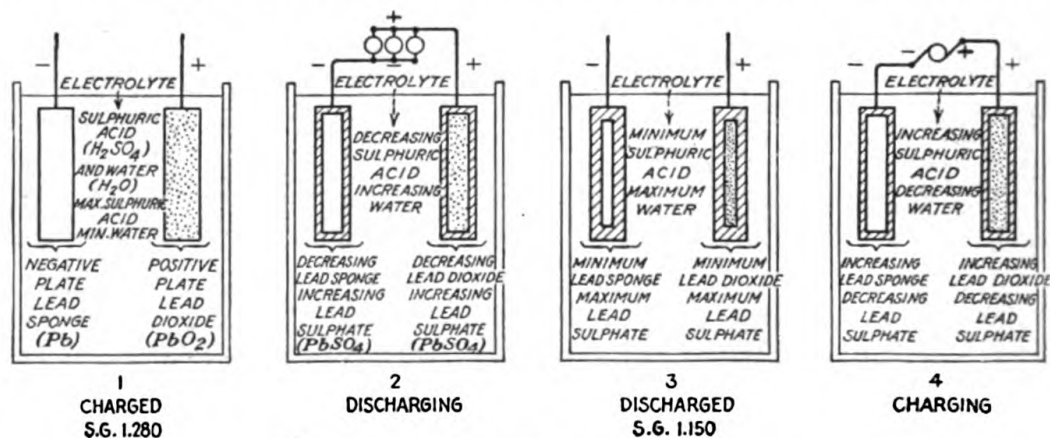


FIG. 18-7.—Chemical action in a lead cell.

charged reading, the cell is considered as being discharged. This drop varies for different size cells.

Period 3 is the cell in a discharged condition when the electrolyte consists of a minimum amount of acid and a maximum amount of water. The porous active material is now clogged up and coated with lead sulphate and the action of the acid on the active materials of the plates is considerably slowed down which causes the voltage of the cell to drop. Although in this condition the plates are sulphated, their condition is not serious, that is, the sulphate can be removed; and it is easily removed if the battery is placed on charge shortly after discharge and before the sulphate hardens.

Period 4 shows the cell on charge. The chemical action taking place now is the reverse of that of period 2, the acid is coming out of its combination with the active material and is being restored to the electrolyte. The lead sulphate is changing back to its original form of sponge lead and lead dioxide. The cell is not fully charged until all, or nearly all, of the lead sulphate has gone from the plates. The life of a lead cell is often shortened because the cell is given only a partial charge; that is, all of the sulphate is not removed from the plates and it becomes hard. This hardened sulphate tends to clog the active material, which is ordinarily porous, so that the acid cannot make sufficient penetration to cause the cell to operate properly. Therefore, the capacity of the cell is reduced by this hardened sulphate, and the cell is *sulphated*.

The combined reaction is expressed: $\text{PbO}_2 + \text{Pb} + 2\text{H}_2\text{SO}_4 \rightleftharpoons 2\text{PbSO}_4 + 2\text{H}_2\text{O}$.

18.9. Specific Gravity and the Hydrometer. *a. Specific gravity*, when applied to liquids, is a convenient method of comparing the weight of a given volume of liquid with a like volume of water. This gives a numerical value which means that the liquid, to which the value applies as a specific gravity, is that many times heavier than water.

$$\text{Specific gravity} = \frac{\text{weight of liquid}}{\text{weight of equal volume of water}}$$

Therefore, when it is said that an electrolyte has a specific gravity of 1.275, it means that, volume for volume, the electrolyte is 1.275 times the weight of pure water.

b. The hydrometer is an instrument for measuring specific gravity. It is used particularly in storage-battery work to measure the specific gravity of the electrolyte and thus indicates the state of charge of the lead-acid cell. The reason why the specific gravity of the electrolyte indicates the state of charge of the cell has already been explained. The hydrometer proper consists of a glass tube 3 to 5 in. long, having a small bulb on one end filled with shot or mercury so that it will float in an upright position when placed in the electrolyte. In accordance with Archimedes' principle which states that *the loss of weight of a body in a liquid is the weight of the displaced liquid*, the hydrometer may be calibrated to show the weight of the liquid compared with the water it displaces. The calibration which shows this value is called the *specific-gravity scale* and appears on the stem of the hydrometer.

In open-jar batteries it is only necessary to float this hydrometer in the electrolyte to take a reading, but for portable use a hydrometer syringe must be used.

c. The hydrometer syringe (see Fig. 18-8) consists of a glass barrel or tube, a hydrometer which fits inside the glass barrel, a small soft- or hard-rubber tube for reaching the electrolyte, a rubber bulb which fits on one end of the barrel, and a soft-rubber plug for joining the barrel to the tube.

To take a reading, insert the rubber tube in the cell, squeeze the bulb, and then slowly release it, drawing up just enough electrolyte from the cell to freely float the hydrometer, making sure that the stem of the hydrometer does not strike the tube at the top of the barrel. The reading on the stem of the hydrometer at the surface of the liquid is the specific-gravity reading of the electrolyte. After testing, the electrolyte must always be returned to the cell from which it was taken.

If a record is kept of the specific-gravity reading of a cell, it is well also to record the temperature and level of the electrolyte, as both of these factors affect the gravity reading to a certain extent.

After adding water, a hydrometer reading should not be taken until the water added has been mixed with the electrolyte by charging the battery until it gasses.

Great care should be taken in handling the acid taken up by the hydrometer syringe, and the syringe hose is best left in the cell while the reading is taken; that is, do not lift up the hydrometer syringe when it is full of electrolyte. Electrolyte has a very destructive effect on clothing and unprotected wood and metals. If accidentally

spilled, its effects may be neutralized by *immediately* applying and washing with ammonia or sodium bicarbonate in liberal doses.

d. *Temperature Correction.*—Since electrolyte, like most liquids contracts when heated, its specific gravity is affected by a change in temperature. If electrolyte has a certain specific gravity at a temperature of 80°F. and is heated, the heat will cause the electrolyte to contract and, although the actual strength of the solution will

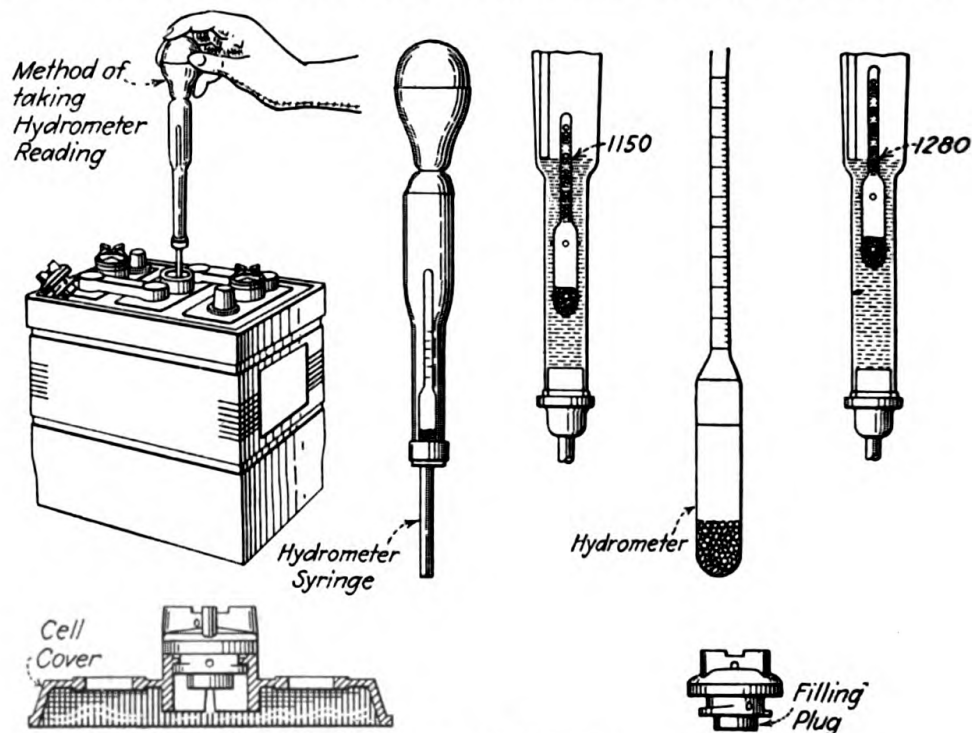


FIG. 18-8.—Hydrometer.

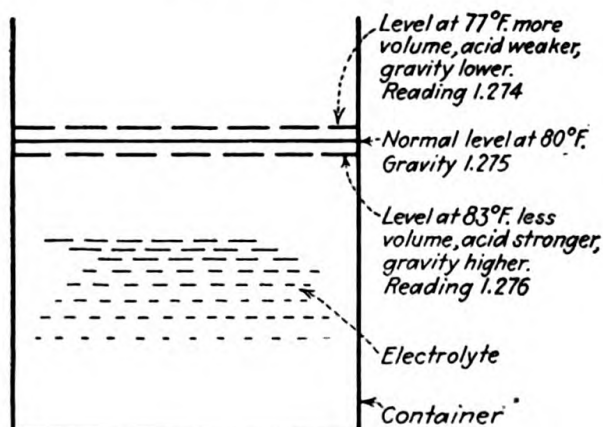


FIG. 18-9.—Temperature correction for specific-gravity reading.

remain the same as before heating, the contraction will cause it to have a **higher gravity**, an increase of approximately one point (0.001) for each 3°F. rise in temperature. For example, if electrolyte has a specific gravity of 1.275 at 80°F. and the temperature is raised to 83°F., this increase in temperature will cause the electrolyte to contract and the gravity to rise from 1.275 to 1.276.

On the other hand, if the temperature has been lowered from 80 to 77°F., this would cause the specific gravity to drop from 1.275 to 1.274. Since change of tempera-

ture does not alter the strength of the electrolyte, changing its specific gravity only, the gravity reading should be corrected one point for each 3°F. change in temperature.

For 1.210- and 1.275-gravity batteries, 77°F. is considered as normal. From this point, correction is made as follows: for every 3°F. rise in temperature, add one point (0.001) to the hydrometer reading, and for every 3° drop below these temperatures, subtract one point (0.001) from the specific-gravity reading. The reason for this correction will become clear by studying Fig. 18-9, which is properly labeled to show the reasons for the changes.

18.10. The voltage of the lead cell is approximately 2 volts on an open circuit, but is higher than this when the battery is being charged, and lower when being discharged. The nominal voltage of a battery is, therefore, the number of cells multiplied by two.

The voltage at any time on discharge or charge depends upon several factors, such as the current rate, the state of charge or discharge, and the temperature. No general averages to cover all conditions can, therefore, be given. The average cell voltage during a 6- to 8-hr. discharge at normal rates is about 1.95 volts with a final voltage of about 1.75 volts. As soon as the cell is put on charge, its voltage rises to about 2.15 volts and then increases during charge until at the end it is between 2.4 and 2.65 volts, depending upon local conditions. The average voltage during entire charge is usually considered 2.33 volts.

18.11. Discharge Rates and Limits. *a. High discharge rates* (amperes) are often confused with overdischarge, a condition resulting when too many ampere-hours are taken out. The effect on the battery of one as against the effect of the other is, however, markedly different.

Any properly designed lead cell may be discharged, without injury to the plates, at *any rate of current* that it will deliver. The maximum permissible rate of discharge is limited only by the current-carrying ability (capacity) of the wiring, motor, or other load to which the battery is connected or by the current-carrying ability of the cell terminals and connectors and not by the plates themselves. This means that, if the circuit external to the plates is of sufficient current-carrying capacity, the cells may be actually short-circuited without buckling the plates or injuring the active material.

The number of ampere-hours which may be obtained from a battery is greater for a long, low- or intermittent-rate discharge than for a short, high-rate discharge. This is because the voltage drops faster at the higher rates.

All batteries are given a *normal* capacity rating which is the ampere-hours obtainable under certain working conditions. Therefore, this so-called normal capacity is not the capacity obtainable under all conditions. For example, a battery may be given a normal 8-hr. capacity rating in ampere-hours, but greater capacity can be obtained if the discharge-current rates are made lower. On the other hand, if the rates are above normal, the capacity for such a discharge will be less.

In an emergency, little if any permanent harm will result if the battery is discharged to the full amount that it will give, provided that it is promptly recharged.

It has already been pointed out that the drop in specific gravity of electrolyte should not exceed a certain definite number of points for the particular battery in question.

b. The danger of harm from overdischarge may be illustrated by a comparison between the active material of the plates and the action which goes on when some of the electrolyte is allowed to act on the copper wire at the terminals of a battery. It is noticeable that a comparatively large amount of copper sulphate is formed when only a small quantity of the metal is eaten away by the acid. In the same manner, when acid combines with the lead in the active material, the resulting lead sulphate occupies more space than the active material from which it is formed. The active material of all battery plates is porous, and this expansion of the sulphated material is accommodated by reducing the size of the pores in the active material. All battery plates are designed to accommodate a certain amount of this expansion of the active material during sulphation, and, in batteries of the type under consideration, this is limited to the amount represented by a certain drop in specific gravity.

c. Further discharge, even if it can be obtained at a satisfactory voltage, results in an excessive expansion, which so closes the pores in the active material that it becomes increasingly difficult to recharge the battery properly after an excessive discharge, and, unless a proper recharge is given, the battery is likely to deteriorate. For this reason the discharge of any battery should not be carried beyond the full-discharge point, as indicated by a hydrometer or ampere-hour meter reading.

18.12. Charging and Charging Rates.—In order to restore a secondary cell (storage battery) to a full-charged condition, it is necessary to reverse the chemical action which occurred during discharge. This may be done by forcing a current through the battery in a direction opposite to the direction of flow of the discharge current. It is evident, therefore, that only a direct current may be used to charge a storage battery. If alternating current only is available at the point where the battery is to be charged, the alternating current must be rectified into a direct current before it can be used for charging purposes.

To cause the charging current to flow in the reverse direction to the discharge current, the positive side of the charging line must be connected to the positive terminal of the battery. The voltage and current values to be used on the charging line will be discussed in Sec. 18.14, on Charging Methods. These values vary, depending on the job to be done. It is, of course, apparent that the voltage of the charging line must never drop below the voltage of the battery on charge, otherwise the battery

would discharge instead of charge. Generally, a charging-line voltage of 2.5 volts per cell is figured for lead batteries.

While a battery is being charged, the amount of sulphate on the plates decreases, and the ability of the plates to give up the acid becomes reduced; in other words, during the early part of a charge the plates can give up the acid at a rapid rate, as there is a large amount of sulphate available. Therefore a battery that is considerably discharged can be charged at a high rate, but, as the charge approaches completion, currents at high rate cannot be utilized, and, if high rates are maintained, only a portion of the current is used to withdraw acid from the plates, and the balance of the current acts to decompose the water in the electrolyte into oxygen and hydrogen, which are given off in the form of gas. Gassing of the battery, therefore, at any time shows whether or not the charging rate is too high. Consequently, when the cells are gassing on charge, the rate of charge should be reduced, so as not to waste the current. Furthermore, the action of the bubbles of gas escaping from the pores of the plates and in "boiling" to the top of the electrolyte have a tendency to wash and wear the active material away from the plates, particularly from the positive plate.

It is a well-known fact that batteries wear out. This wear shows itself to the eye principally in the positive plate, the active material of which softens with use, and, were it not for this unavoidable fact, the life of batteries would be very much longer than at present. As the active material of the plate softens with use, there is a tendency for the softened material on the surface of the plate to fall to the bottom of the jar in the form of sediment. The action of the gas in escaping from the pores of the plates, and the little whirlpools created in the electrolyte when the bubbles of gas boil to the surface, hasten this shedding of material and shorten the life of the battery.

Excessive gassing, therefore, should be avoided if the best life of the battery is to be obtained. A small amount of gassing at low rates and for a short time, at the completion of a charge, is not objectionable, but violent gassing having the appearance of boiling should be avoided. This means that overcharging is bad for the battery.

The value of the charging current at which appreciable gassing begins depends upon several factors, such as state of charge, temperature, specific gravity of electrolyte or type of plate, but the principal factor is the state of charge of the battery. When a battery is fully charged, any rate of charge, however small, will produce gassing, but the rate may be reduced to such a low value that, unless abnormally prolonged, the small amount of gassing which results is practically harmless. This safe rate is called the *finishing* rate. During the earlier stages of the charge, the charging rate may be several times the finishing rate, without producing violent gassing; and the more completely the battery is discharged the higher the charging rate may be without causing excessive gassing.

With the above limitations in mind, it is advisable to charge a battery at relatively low rates if local conditions permit. Of course, the lower the rate of charge, the longer the time required to complete the charge. If 8 to 14 hr. are available (the exact time depending upon local conditions), the entire charge may be given at a low rate, not exceeding the *normal* or *finishing* rate for the particular cell in question. If this length of time is not available, the charging rate should be higher at the start of charge and then reduced to the rate mentioned as soon as the battery begins to gas.

Where an ampere-hour meter is used, the following general arbitrary rule can be given: The charging rate in amperes must be *less than* the ampere-hours still out of the battery until the finishing rate is reached. In other words, the ampere-hour meter will always indicate a rate which should not be *exceeded* at that time. Of course, any rate less than that indicated by the ampere-hour meter will be satisfactory.

The important points are: Avoid gassing and keep the cell temperature below 110°F.

The normal charge and discharge rates are values of current arbitrarily assigned on the basis of economical battery service. As related to discharge, this means the discharge rate at which the cost of watt-hour service is at its lowest for the work in hand. As related to charge, the normal rate is that rate at which the batteries can be most economically charged in commercial service. This applies to all types of lead-acid or Edison storage batteries.

18.13. Charging Requirements.—The instructions issued by the battery manufacturer for the particular type of battery to be charged should always be carefully studied and followed. Batteries in different

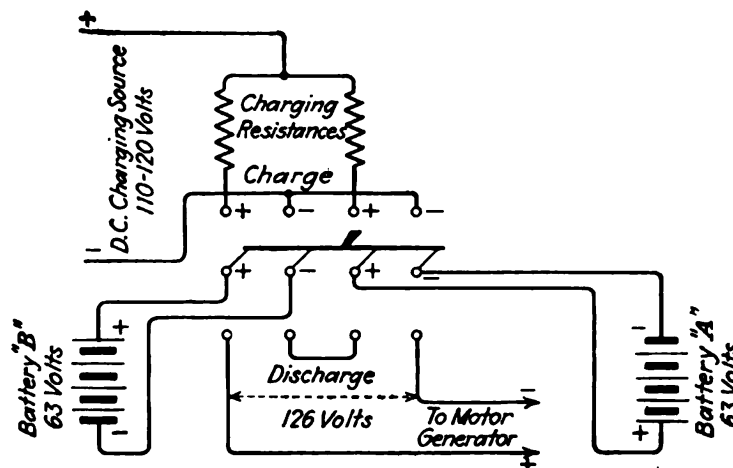


FIG. 18-10.—Method of charging batteries in parallel banks and discharging in series.

classes of service require different methods of charging and are either *cycled* or *float*ed as will be explained later.

a. Marine Emergency Batteries.—The large installations of 60 cells designed to provide emergency power if the ship's generator fails are usually of the portable (1.250 to 1.275 sp. gr.) type and, when not in use, are permanently connected across the ship's line through a high resistance which serves to keep them fully charged and ready for operation at all times. This is the *trickle-charge* method, and the battery is said to be *float*ed on the line. It is, of course, necessary to divide the bank of 60 cells into two groups of 30 cells each (by means of a switch) for charging, as shown in Fig. 18-10, in order that the battery voltage may not exceed the line voltage, which would generally happen if the 60 cells were thrown across the line in series.

If an emergency discharge is necessary, the battery should be immediately recharged at the normal rate (not trickle charged) after which it may be float

The trickle-charge or floating-charge system is designed to compensate for local action, which causes the battery to discharge slowly when not in use, and it should keep the battery full charged at all times after it has once been charged at the normal rate. The floating operation should be checked every week or so, until it is certain that the system gives neither too much nor too little charge. With proper adjustment, the specific gravity of a selected cell, which is always used for the purpose and, therefore, known as the *pilot cell*, will remain practically constant (within 5 to 10 points, if the level of the electrolyte is kept the same height) and the cells will not be gassing. If the cells gas continually, the battery is receiving too much charge. If the gravity continues to drop, the battery is not receiving enough charge. The charging current may be adjusted, if necessary, by changing the resistance in series with the batteries (usually lamps), using higher wattage lamps to increase the current, or lower wattage lamps to decrease the current, or, if resistance units are used, they may be varied. Another check may be made a week or so later, repeating until it is certain that the system gives neither too much nor too little charge. The adjustment may then be considered correct and will only require occasional checking. The pilot cell should not always be the same cell. An occasional change in the cell selected for purpose should be made.

To facilitate the operation of the battery, it is advisable to record three or four times a year the specific gravity of each cell.

Smaller ship-radio battery installations are usually cycle charged, that is, they are not floated across the line but allowed to reach a certain state of discharge, then are placed on charge at their normal rate.

The *normal rate* is any rate of current which will charge the battery in the shortest possible time without undue gassing. In other words, the normal rate is the maximum current which can be passed through the battery while on charge without excessive gassing.

b. Broadcasting or Other Land-station Batteries.—Batteries in this class of service are usually of the stationary type with a full-charge gravity of 1.210. For plate- and filament-power service the batteries are of the sealed-glass-jar type. In some of the larger stations it has been necessary, because of the large filament loads, to use cells in open lead-lined wood tanks.

Regardless of the type of battery used, they may be cycle charged or floated, depending upon the number of hours they are used each day. If the battery is used only a few hours each day, and if it carries the load for several hours or the greater part of the day, it is floated.

When a battery is floated across a plate generator, it acts as a filter ironing out any irregularities in the output voltage of the generator, thus making the plate voltage as close to the ideal pure direct-current supply as it is possible to get unless batteries are used solely as the source of

power. This is a particularly practical way of getting a constant source of well-filtered direct current for use on speech-input equipment.

18.14. Charging Methods. *a. Floated Batteries.*—By *floated* batteries, such as are used in some broadcasting and other land stations, are meant those which are continuously connected to the electrical system with which they are used in such a manner that they are normally kept fully or nearly fully charged (except for momentary or emergency discharge) by being constantly maintained at a voltage that will result in a small net charge. The *floating rate* is the sum of the very low current (generally termed *trickle rate*) required to counteract the small internal battery losses plus the average current requirements for the remainder of the circuit. If the latter is zero, the floating rate required becomes the trickle rate for the battery. The required floating or trickle current is automatically provided when the proper voltage is maintained across the battery.

For floated batteries of the 1.210 specific-gravity types, the voltage *directly at the battery terminals* should average very close to 2.15 volts per cell (for example, 129 volts for 60 cells in series) and should be kept between 2.10 and 2.20 volts per cell. If it is continually below 2.10, the charging is insufficient, in which case gravity readings taken from time to time will show a gradual falling off. If continually above 2.20, charging is excessive, in which case unusually frequent addition of water will be required and short life will result. Adjust as necessary until the voltage holds between these limits. Variations outside of these limits, if only of a few minutes' duration, are not harmful and may occur as incidental to normal good operation.

It is very necessary that the voltmeter used be kept in careful calibration, as an error of 5 per cent or even less might have considerable effect upon the reliability and life of the battery.

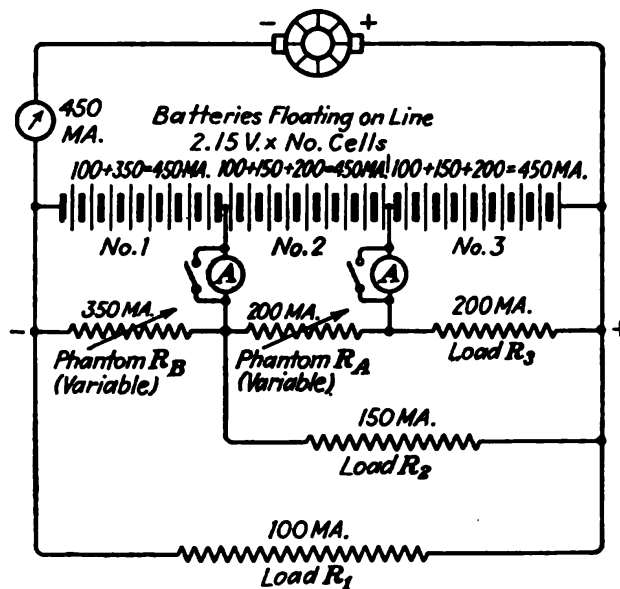
With the proper voltage across its terminals, the actual current taken by the battery at any time depends on (1) the condition which the battery has had to meet prior to the time under consideration, (2) temperature of the battery, (3) age of the battery. But these variations are in all cases corrective; that is, the battery takes such current as is necessary to keep it in proper condition. This makes it impossible to assign definite values to the current which might be read on an ammeter in the battery circuit, and, therefore, makes voltage operation of the battery much more satisfactory than current operation. However, it may be stated that at normal temperature the normal current flowing to a fully charged battery that has been under constant voltage of 2.15 volts for approximately 1 hr. or more should be between $\frac{1}{4}$ and 1 per cent of the 8-hr. rate of the battery. At higher temperatures or if a discharge has been recently taken (such as a circuit-breaker movement), a current in excess of this will be observed. At lower temperatures, or if the battery has been subject to higher voltage, the observed current will be less or in the latter case may even be temporarily in a discharge direction. If the trickle rate is consistently less than $\frac{1}{4}$ per cent or more than 1 per cent of the 8-hr. rate of the battery, it is recommended that the meters be checked.

Attention is called to the fact that in some cases it is not practicable to connect permanently an ammeter in the battery circuit to indicate the amount of the floating current, as any high-discharge currents required would, of course, pass through the meter in a reverse direction.

These instructions apply to a battery that is floated continually, 24 hr. daily; but in certain broadcasting stations where the battery is used only when the station is in operation (which may be 18 to 20 hr. daily), the battery is floated on the generator for this length of time at 2.15 volts per cell. In certain installations, duplicate sets of batteries are installed and the sets alternated. One set will carry the load while the other set is on open circuit. Floating the load at 2.15 volts per cell for the 18 to

20 hr. the station is operating will prevent the battery thus floated from discharging, the load being carried on the generator (the primary purpose of the battery in these installations is that they act as filters). But as this voltage is only just high enough to give the battery a small amount of charge, but not enough to bring it up to a state of full charge, an equalizing charge (to be explained later) must be given once a month to bring the battery up to full charge.

Some plate-battery installations require that taps be taken off for different voltages. Under these circumstances the load across the several groups of cells will be different, and therefore some cells will be discharged more than others. Therefore, on recharge, if the heaviest worked group receives the correct amount of charge, the other two groups will receive too much charge. To remedy this situation it is necessary to connect phantom-load resistors across all groups except the group handling the largest current drain, and, by means of these resistors, adjust the load across each group so that the value of the load is the same across each group. This is shown by the schematic diagram in Fig. 18-11. These phantom resistors are taken out of the



Ammeters A, A are zero-center meters

FIG. 18-11.—Circuit for floating battery on line, utilizing phantom load resistors to equalize discharge.

circuit when the batteries are on open circuit. A voltmeter which can be connected across each section of the battery by means of a plug-and-jack arrangement, or separate voltmeters across each group or section, is advisable in order that the voltage may be held constant across each group at 2.15 volts per cell. When duplicate sets of batteries are provided the sets are changed over from open circuit to floating every 24 hr. As mentioned before, an equalizing charge is then given once a month to bring the cells up to full charge.

b. Equalizing Charge.—An equalizing charge is a charge at a rate not higher than the finishing rate for the particular battery, and lower, if practical, and continued until all the cells gas freely and until five consecutive readings of the specific gravity of the pilot cell (or of the lowest gravity cell) show no further increase over a period of time; this period of time and the interval between the consecutive readings being shown in the table below. The charge may be given by maintaining approximately constant either (1) the charge rate into the battery (constant current method) or (2) the voltage across the battery terminals (constant voltage method).

Interval between readings	Period of time for five readings	Constant-current method charge rate	Constant-voltage method average volts per cell
15 min.	1 hr.	Finishing rate	
30 min.	2 hr.	$\frac{1}{2}$ of finishing rate	2.40 volts
1 hr.	4 hr.	$\frac{1}{4}$ of finishing rate	2.35 volts
2 hr.	8 hr.	$\frac{1}{8}$ of finishing rate	2.30 volts
3 hr.	12 hr.	.....	2.27 volts

In operation which includes frequent charges, the equalizing charge is simply an extension of one of the ordinary charges.

c. Cycled Batteries.—By *cycled* batteries are meant those which are normally allowed to reach a certain state of discharge before being placed on charge, the charge being started manually.

The battery may be charged at any rate in amperes that will not produce gassing or bubbling of the electrolyte or a cell temperature in excess of 110°F. (43°C.). As soon as gassing starts, or before if the temperature reaches this limit, the rate should always be reduced, and the charge should be completed at not higher than the finishing rate. *Do not charge at a higher rate than this while the cells are gassing.* If charging at constant current (Sec. *d*) is more convenient, the entire charge may be given at the finishing rate or at a lower rate.

The best method of charging a battery will depend on the number of cells in the battery, the time available for charging, and the voltage and capacity of the charging apparatus. Wherever possible the charging equipment should be permanently arranged so that the rate of charge is automatically (and not manually) tapered to the finishing rate or to less, by the time the charge is completed. Usually, this is not only possible but very easy and simple to arrange by the aid of a fixed series resistance in the charging line.

Charge the battery at least frequently enough to keep the specific gravity of the electrolyte from falling below the discharged limit.

If the battery has been completely discharged, it should be charged promptly and not allowed to stand completely discharged. Part of a charge is better than none, but it must be remembered that a charge longer than usual is required after a long discharge. Ordinarily too much charge is harmful, but in such a case it is better to give too much charge rather than too little.

The battery should be charged at least once every 6 months.

If the battery has been idle, it should be given a prolonged charge just before using it, continuing until the gravity stops rising.

If the battery requires less than one charge a week, make every charge an equalizing charge.

If the battery requires more than one charge a week, charge until the cells are gassing and until the specific gravity of the pilot cell is within 5 to 10 points of the maximum obtained on the last equalizing charge. *Then stop the charge.* Every sixth or seventh charge should be continued into an equalizing charge.

d. Constant-current Charging.—In the absence of a method of controlling the charging voltage at the source, it is necessary to use the constant-current method of charging. This means that the current remains constant until changed manually.

The constant-current method of charging utilizes a source of charging voltage that is nonadjustable. The battery to be charged is connected across this line in series with a charging resistor which allows the desired amount of current to pass to the

battery. In the event that a charging resistor is not available, one or more incandescent lamps in parallel may be used to pass the required current.

It is a convenient practice to charge a battery at the 8-hr. rate so as not to overload the charging line. It is necessary, also, to put into a battery about 10 or 15 per cent more ampere-hours than is taken out on discharge. For a 120-amp.-hr. battery fully discharged, therefore, it is necessary to put in approximately 135 amp.-hr., depending on factors that affect the capacity of the battery. Thus a 120-amp.-hr. battery to be charged at the 8-hr. rate would require approximately $135 \div 8 = 17$ amp. If we use a parallel bank of lamps to pass this current from a 110-volt line, the current each lamp will pass can be calculated by the formula $I = W/E$, where E is the voltage of the line on which the wattage is based, usually 115 volts. Thus a 100-watt lamp would pass a current of 0.83 amp. To pass 17 amp., $17 \div 0.83 = 20$ lamps in parallel (close enough) would be needed.

To prevent excessive gassing at the termination of the charge, the current passed by the lamp bank may be gradually reduced by unscrewing one lamp at a time from the circuit. Thus the current can be gradually reduced in steps of 0.83 amp. to a final value of 0.83 amp. (trickle-charge rate) if desired.

The constant-current method of charging is not so efficient as the constant-voltage method because of the power lost in the series resistance and in gas and heat in the battery.

In the absence of an ampere-hour meter or information as to the ampere-hour capacity still remaining in the cell on which to base a charging rate, it would be perfectly safe to take assumed values as long as they are within the limits of the battery capacity and the load limit of the charging line. For example, if the correct charging rate is not known, it would be safe to use a rate of 10 to 20 amp. at the start, but it would be advisable to watch the gassing of the battery and the temperature of the electrolyte. If the cells tend to gas heavily, or the electrolyte tends to approach $110^{\circ}\text{F}.$, the rate should be reduced to a safe value.

The correct charging current near the end of a charge can be gaged by the gassing of the cell. If the cell does not gas, the current is not too high. More lamps might be introduced into the parallel bank, a few at a time, until gassing appears to indicate that the current limit has been reached. One or two lamps should then be removed to reduce the gassing to a small amount.

18.15. Effect of Temperature on Operation.—The cell temperature should not exceed $110^{\circ}\text{F}.$ The effect of high temperature is primarily to shorten the life of the wood separators which are installed between the positive and negative plates.

There is always a tendency for wood in contact with sulphuric acid and oxygen to become carbonized. This tendency is much accelerated at temperatures in excess of $110^{\circ}\text{F}.$; and, if a battery is regularly operated at temperatures in excess of this amount, it will probably be necessary to renew separators in the entire battery prior to the time the battery itself ends its useful life. A perforated rubber separator between the positive plate and the wood separator will help to lengthen the life of the wood separator.

In the materials used in any commercial storage battery, some impurities are also present which cause very slight action in the cell, even when it is not in active operation. At high temperatures, these internal losses are increased, as is evidenced by the fact that a battery

placed in storage will not lose its charge seriously over a period of, say, 6 months if kept in a cool place. If kept at a temperature around 100°F., it will lose much more of its charge in, say, 3 months.

In operation, however, the principal effect of high temperature of a battery is its deteriorating effect on the separators and plates.

In the case of cells in rubber jars, if temperatures much in excess of 110°F. exist, there will follow a softening of the sealing compound and a warping of covers of the cells, so that the sealing of the cells will lose its effectiveness. Stopping of the electrolyte will result, leading to deterioration of the wood trays in which the cells are assembled.

Temperature has quite a marked effect on a battery. Low temperature temporarily decreases both the discharge voltage and the ampere-hour capacity which can be taken out of the battery. It is as if the battery were numbed by the cold and unable to make the same effort as at normal temperature. The effect of cold is only temporary, the battery returning to its normal state upon its return to normal temperature even without charge. There is no danger of the electrolyte freezing in a fully charged cell, but in one which is overdischarged or has had the water added without subsequent charging this is likely to occur. Freezing may crack the battery jars owing to the expansion of the electrolyte and for this reason should be guarded against.

18.16. Gas and Ventilation.—The hydrogen and oxygen given off from the battery during charge, when unmixed with a large amount of air, form a combination that will explode violently if ignited by an open flame or an electric spark. The battery compartment should, therefore, be open while the battery is being charged, in order that these gases may become mixed with air. Do not bring exposed flame, match, candle, cigar, and so forth, near the battery when charging or shortly after. If the battery is to be charged in a closed room, especial attention should be paid to ventilation.

18.17. Effect of Wrong Charging Polarity.—It is very important that the positive side of the charging line be connected to the positive side of the battery to be charged. It is readily seen that, inasmuch as the object of the charge is to reverse the chemical action which took place during discharge, the current must flow in the opposite direction to the way it flowed during discharge. If, by accident, the polarity of the charging line is reversed, the chemical action which took place during discharge will be continued, and the effect is to make the negative plates brown and the positive plates gray and to buckle the outside negative plates.

The remedy for a reversed charge is to discharge the cells completely to get rid of the charge in the wrong direction, then short-circuit them as long as current flows (connect a wire across the terminals), and then charge them in the right direction at a reduced rate until the specific

gravity reaches a maximum and remains constant for 5 hr. This may require approximately 40 hr., more or less, depending on the type of battery. Under certain conditions the outside negative plate may need straightening. If the battery is operated reversed for any length of time, the negatives will rapidly throw off their material and become useless.

The polarity of the charging line may be determined by a direct-current voltmeter, the terminals of which are marked with the positive (+) and negative (−) signs; the dial pointer will tend to read backward if not properly connected across the line. The positive terminal of the voltmeter must connect to the positive side of the line for the meter to operate properly, and in this way the polarity of the line is indicated.

If a suitable voltmeter is not at hand, the polarity of the line may be determined on circuits of 110 volts or less by dipping the ends of two wires connected to the circuit in a glass of water in which a very small amount (a few pinches) of common table salt, potash, or acid electrolyte has been dissolved. Keep the wires about 1 in. apart, and be very careful not to short-circuit the line. When there is current flowing, gas bubbles will form on both wires, but the wire where the greatest amount of bubbles forms will be the negative side of the line.

Another convenient method of determining polarity is to touch a wet piece of blue litmus paper with two wires from the line, holding them so they touch the paper about $\frac{1}{4}$ in. apart. A red mark will appear at the point where the positive wire touches the paper, if a current is flowing.

Lacking a voltmeter it is perhaps safest to test the polarity of lines carrying voltages between 100 and 550 volts by connecting a neon bulb to the line. This bulb being unidirectional in operation will glow only if, when connected to a direct-current circuit, its anode is connected to the positive side of the line. The polarity of the line becomes apparent from the operation of the tube. A simple line-testing tool using this principle is now on the market.

The polarity of the charging current should be noted before each charge, especially on small installations where no meters are provided to indicate line condition continuously. This is especially necessary on board ship in the event that the polarity of the ship's generator has been reversed in the engine or dynamo room after a shutdown or change-over.

18.18. Sulphation and Remedies. *a. Causes.*—Sulphation is such an important phenomenon in connection with the lead storage battery that it is worth while to risk repeating certain points already explained in order to give the matter complete treatment here. During any discharge of a battery, there is being formed sulphate of lead, without which there would be no production of current. If, however, charging is neglected, the sulphate reaches a condition which tends to fill the pores of the plates and make the active material dense and hard. It is this condition which is ordinarily referred to as "sulphated."

To keep a battery in good condition, however, it is neither necessary nor desirable to continue *every* charge until maximum specific gravity has been reached, indicating that no sulphate remains in the plates. A few points less than maximum is sufficient, provided the equalizing charge to maximum specific gravity is given at regular intervals, or, in the case of floated batteries, provided the voltage at the battery terminals is kept within proper limits.

In keeping a battery from becoming sulphated, do not go too far in the other direction and ruin it by overcharging.

The normal lead sulphate formed on discharge of the battery is in a form which absorbs the charge very readily.

When a battery is sulphated, as ordinarily expressed, the sulphate is denser than normal and does not absorb the charge readily, but only with difficulty. When in this condition, the ordinary charge is insufficient.

The cause of this condition is some form of abuse, such as:

Standing discharged.

Habitual undercharging.

Neglecting evidence of trouble in individual cells.

Adding electrolyte or acid to raise the specific gravity, instead of bringing it out of the plates by proper charging.

The active material of sulphated negative plates is generally of light color, and either hard, or granular, gritty, and easily disintegrated. It is the negative plates which require the prolonged charge necessary to restore a sulphated battery.

The last stage of extreme sulphation of negatives is that in which the material deteriorates into what may be described as a mushy condition. This condition almost always results from adding acid to the cells—the “drug-store charge.” No treatment is known that will restore cells which have been abused in this manner.

Sulphated positives, unless physically disintegrated or badly buckled, are but little changed in general appearance and can be restored to operative condition, although their life will not be so great as if they had not been subjected to this abuse.

Sulphated plates should be handled as little as possible.

The user is frequently too ready to conclude that his battery is “sulphated” every time the results obtained are not fully up to his expectations.

If the sediment in a battery has not been allowed to reach the bottom of the plates, and the level of the electrolyte has been properly maintained by restoring level lowered by charging and evaporation with approved water, the battery can be sulphated only because it has not been properly charged or because acid has been added to the electrolyte. An individual cell may become sulphated by external grounding, by an internal short circuit, or by drying out as might be caused by failing to add water or to replace a broken jar promptly.

A battery is sulphated only when acid is tied up in the plates in the form of sulphate. When the specific gravity of the electrolyte will rise no higher after continued charging, it shows that there is no more sulphate to be acted upon, since, during charging, the electrolyte receives acid from no other source than the plates.

If a battery is thought to be sulphated, charge the battery fully, and discharge it at the normal rate. If it gives its rated capacity at the battery terminals, the reason for apparent lack of capacity should be looked for elsewhere than in the battery.

If the rated capacity is not obtained, follow the treatment outlined below.

When one or more individual cells have become sulphated while the balance of the battery is in good condition, such cells should be treated separately. It is better to remove them from the circuit.

b. The treatment for removing sulphate is to recharge the battery in the regular manner. When it is considered fully charged, take and record a hydrometer reading of each cell and the temperature of several cells. Charge the battery at a rate as near its normal (or finishing) rate as the charging apparatus will permit. If the temperature reaches 110°F., reduce the current or temporarily interrupt the charge so as not to exceed this temperature.

Hydrometer readings should be recorded at regular intervals (say 3 to 5 hr. apart) to determine if the specific gravity is rising or if it has reached its maximum. Continue the charge, recording the readings until there has been no further rise in any cell during a period of at least 10 hr. at the normal (or finishing) charge rate. Increase the length of time, proportionately, for lower rates. Maintain the level of the electrolyte at a constant height by adding water after each reading. If water is added just before taking hydrometer readings, the water would not have time to be mixed with the electrolyte by the gassing resulting from charging.

Should the gravity in any cell rise above the normal value, draw off its electrolyte down to the top of the plates and put in water up to the normal level. Continue the charge, and, if the gravity again goes above normal, it shows that acid has been added sometime during the previous operation of the battery. As much electrolyte as possible should then be removed, replaced with water, and the charge continued, repeating the operation as often as necessary.

The treatment may be considered complete only when there has been no rise in the gravity of any cell during a period of at least 10 hr. of continuous charging.

Upon completion of the treatment, the specific gravity of the electrolyte should be adjusted to its normal value, using water or electrolyte, as may be necessary.

By following the few simple rules of operation given in the following section, all the trouble, time and expense of restoring a "sulphated" battery can always be avoided.

c. Water Treatment.—The water treatment is more or less of a drastic measure, to be attempted only as a last resort where prolonged charges in normal gravity are not effective, except in cases where the gravity has been above normal or where the construction of the cell is such that the work involved in lowering the gravity and afterward raising it is not excessive. In cases where prolonged charging in normal gravity would eventually remove the sulphate from the negatives, the water treatment removes it more thoroughly and in much less time.

This treatment does not benefit the positives. In fact, if the charging in reduced gravity is carried to excess, the positive grids may suffer somewhat. Therefore, it

should not be attempted in cases where positive grids are cracked, formed, or corroded to any appreciable extent.

The water treatment consists of:

1. Reducing the gravity of the electrolyte until it is between approximately 1.050 and 1.100 specific gravity.

2. Charging at the normal (or finishing) rate to both a 20-hr. gravity and a 20-hr. voltage maximum. If the gravity rises to 1.150, electrolyte should be removed and replaced with water, so that the gravity is between 1.050 and 1.100. Repeat this step until the maximum gravity obtained by charging is below 1.150.

3. Increasing the gravity by adding electrolyte and by charging at the finishing or normal rate until at the end of a 3-hr. gravity maximum the gravity is somewhat lower than normal operating value, 1.180 for a 1.210-specific-gravity battery and 1.250 for a 1.280-specific-gravity battery. The specific gravity of the electrolyte cannot be brought back to normal once a cell has required the water treatment.

18.19. Care and Operation of Lead Cells.—At various places throughout this chapter are given various explanations and rules to be followed in the operation of lead cells. Some types of cells will require certain kinds of care not required by other types of batteries. Each installation must be studied for its own requirements. The *instructions* supplied by the battery manufacturer for the particular type of battery should be carefully studied and followed.

The following points are important in the operation of any type of lead-battery installation.

- a. Keep open flames away from the battery at all times during operation.
- b. Replace spilled electrolyte before charging.
- c. When water in cell evaporates, add distilled or other approved water.
- d. Never allow cells to remain in a discharged condition.
- e. Mix electrolyte in clean earthen or glass jars.
- f. Allow newly mixed electrolyte to cool before putting into cells.
- g. Never pour water into acid, injurious action may take place.
- h. Never allow salt to get into cell.
- i. Use only chemically pure acid (not, however, concentrated) and water.
- j. Always provide plenty of ventilation for battery enclosure.
- k. If burned by sulphuric acid, apply ammonium hydroxide (*ammonia*) or baking soda (water paste). Dress with aqueous solution of boric acid (half-saturated) to prevent infection.
- l. Don't charge at too high rate.
- m. Always keep battery charged and ready for operation.
- n. When not in use, keep battery floating on line (usually).
- o. Take frequent full-load voltage readings.
- p. Take occasional hydrometer readings.
- q. Keep level of electrolyte to proper height.
- r. Give battery an equalizing charge monthly.
- s. Keep the batteries clean and their tops dry.
- t. Keep all electrical connections clean and bright and free from corrosion.
- u. Do not add acid unless some has been lost due to spilling or flooding, and not then unless gravity does not come up with charging.
- v. Keep vent plugs in place unless filling cells or taking hydrometer readings.
- w. Never add any special powders, liquids, or jellies to the cells to bring back life; these treatments are useless.

- x. Avoid undercharging and excessive charging.
- y. Keep trays properly wedged.
- z. Establish a routine of battery care.

18.20. Troubles and Their Remedies.—Certain troubles may be encountered in the operation of lead cells and some of the most common of these, in addition to those already treated, will now be covered in detail.

a. *Impurities in the electrolyte* will cause a cell to work irregularly. Should it be known that any impurity has got into a cell, it *should be removed at once*. In case removal is delayed and any considerable amount of foreign matter becomes dissolved in the electrolyte, this solution should be replaced with new immediately, thoroughly flushing the cell with water before putting in the new electrolyte. If in doubt as to whether the electrolyte contains impurities, a sample should be submitted for test.

b. *Sediment* which collects underneath the plates need cause no alarm unless it deposits too rapidly, in which case there is something wrong with the way the battery is operated. In a new battery there is always a thin layer at the start. As the battery wears, the sediment becomes higher, but in batteries which are floated the plates usually wear out before the sediment space is filled.

c. *Excessive Charging.*—Experience shows that one of the most harmful practices from which a radio-battery installation suffers is **overcharging**. This means continuing the charge after the battery has chemically reached a state of full charge. The effect of this excessive charging is that it causes undue wear on the plates and materially shortens the life of the battery by loosening the active material and depositing it as sediment at the bottom of the jar. The positive plates are especially affected. **The only remedy is to stop excessive charging.**

d. *Cracked or Broken Jar.*—A slight crack may go unnoticed for a long time, and considerable water will be added before it is noticed that the electrolyte has been leaking. The plates will not be affected noticeably, but the electrolyte will be weak and will need strengthening by adding acid to replace that lost by the leakage. If the leakage was enough to expose the plates to air and partly dry them, the cell will need some extra charging. Partly dried negative plates always need some excess charge.

The remedy, of course, is to replace the broken jar with a new one. On board ship, however, it is not usually the practice to do this kind of work while under way. In these circumstances the leak might be reduced, or stopped, by applying paraffin, wax, or pitch to the crack. This should be only a temporary measure, and the leaky jar should be replaced as soon as convenient.

If it is not possible to keep electrolyte in the cell on account of the leak, the cell could be disconnected from the bank by cutting the con-

necting strap with a hacksaw and jumping (not short circuiting) the cell with a heavy-wire conductor. It is well not to expose the plates to air, and for this reason the leak should be minimized as much as possible and leakage replaced by adding distilled water to keep the liquid level above the plates. Ammonia or sodium bicarbonate (not washing soda) may be used to neutralize spilled acid or electrolyte, if applied immediately.

II. THE NICKEL-IRON-ALKALINE BATTERY

18.21. The nickel-iron-alkaline cell, manufactured only by the Edison Storage Battery Company and known as the *Edison cell*, differs in all

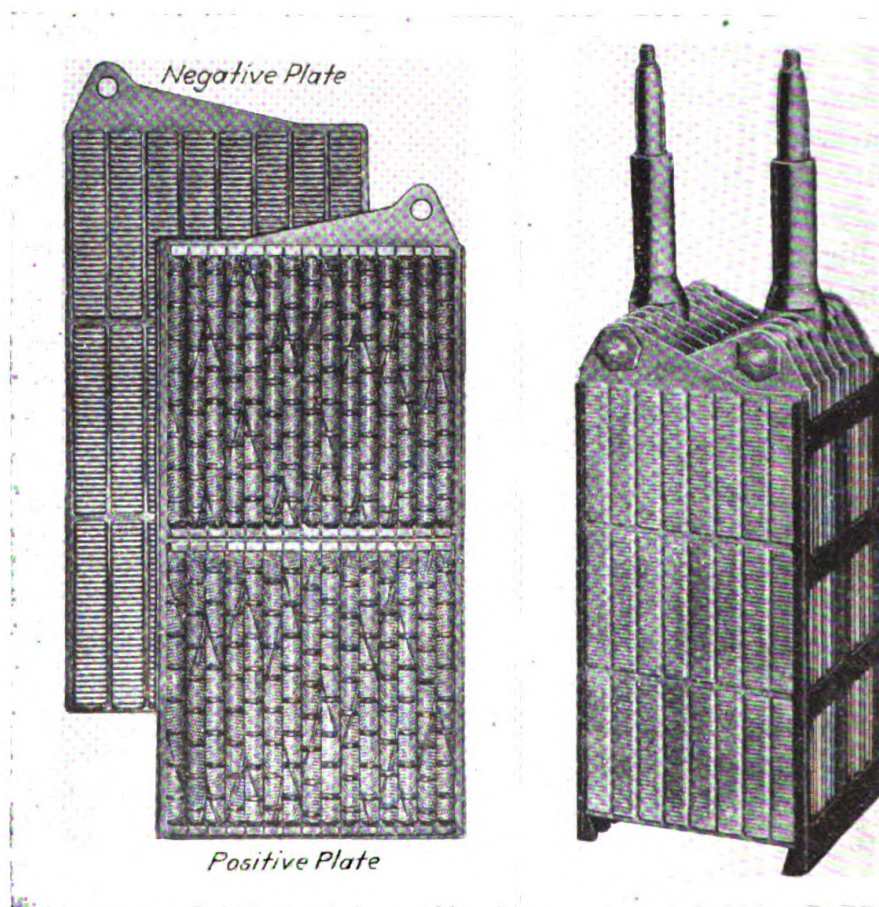


FIG. 18-12.—Positive and negative plates, and element assembly for Edison battery.
(Courtesy of Edison Storage Battery Company.)

respects from the lead-acid cell. The two types differ widely from the standpoint of construction, material used, electrical characteristics, and chemical reactions, and have nothing in common.

a. The positive plate consists of perforated nickeled-steel tubes, arranged in rows and filled with alternate layers of nickel hydroxide and exceedingly thin flakes of pure nickel.

b. The negative plate consists of a grid of cold-rolled nickeled sheet steel holding a number of rectangular pockets filled with iron oxide. The construction and assembly of the plates are shown in Fig. 18-12.

c. The separators used to separate the plates are narrow strips of especially treated hard rubber which is not injured by the electrolyte.

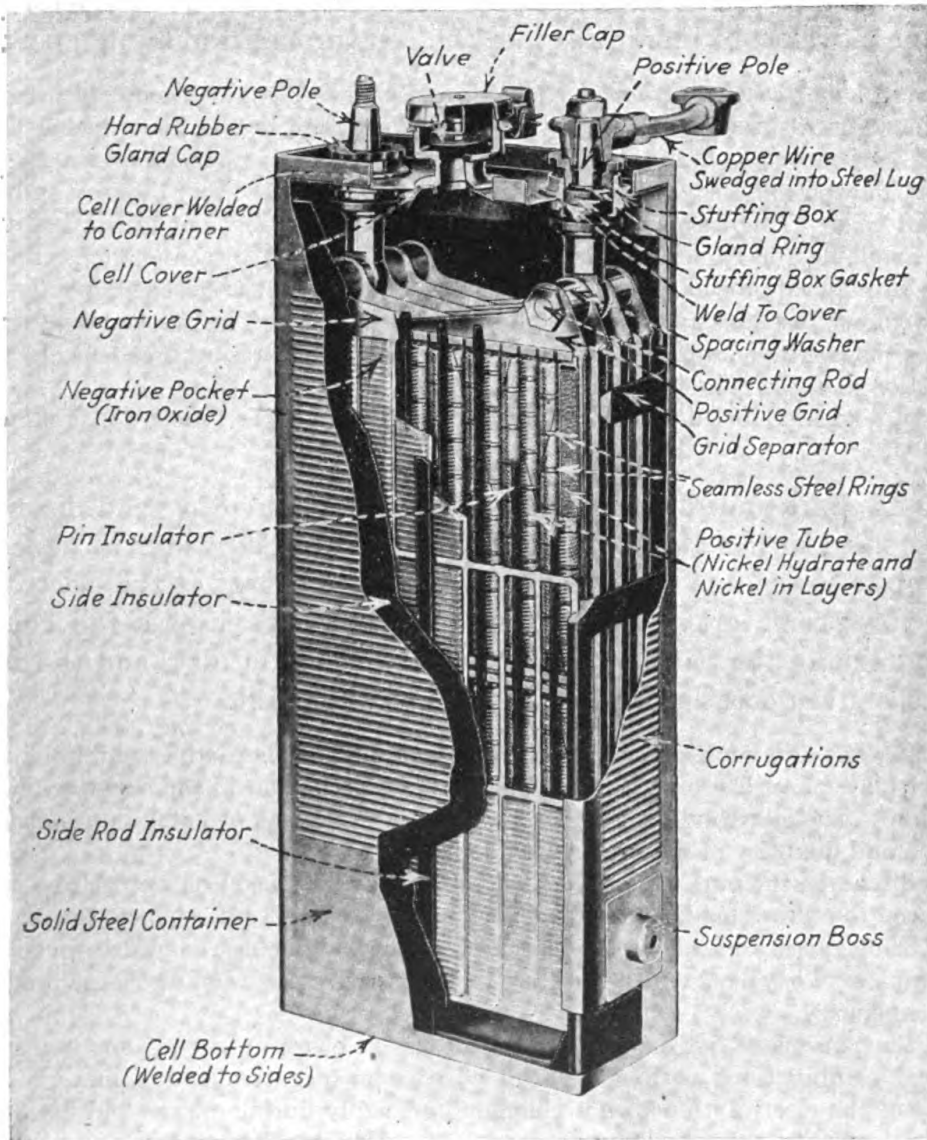


FIG. 18-13.—Edison cell. (Courtesy of Edison Storage Battery Company.)

The grid separators are provided with grooves which take the edges of the plates, spacing and insulating them from the steel container.

d. The electrolyte consists of a 21 per cent solution of potassium hydroxide in distilled water to which is added a small percentage of lithium hydrate. The electrolyte has a specific gravity of about 1.200 at 60°F. and does not vary appreciably in density during charge and discharge. Frequent hydrometer readings are therefore unnecessary as they are no indication of the state of charge.

e. The container is made of cold-rolled nicked sheet steel. Corrugations provide additional container strength, and the soundness of the top, bottom, and side seams is secured by oxyacetylene welding. Each cell is provided with a filling aperture for flushing. The filling-aperture valve is constructed so that it readily permits the escape of gas when the cell is charging but retards spraying the evaporation of the electrolyte and the entrance of impurities into the cell through the filling aperture.

f. Assembly and Connections.—Nickel-iron-alkaline cells are assembled into batteries in various-sized hardwood trays. Steel suspension bosses, spot-welded to the sides of the containers, fit into hard-rubber buttons recessed into the tray slats. Thus assembled, each cell is supported firmly in place and insulated from the tray and from adjacent cells. This tray assembly is flexible and permits efficient utilization of the space available for battery installation. Connecting and disconnecting cells is a simple mechanical process. Forged nicked-steel, tapered lugs swedged upon heavier copper connecting links are used to connect adjacent cells. The internal taper of the lugs fits the corresponding taper of the pole pieces and insures an excellent electrical connection at these points.

A detailed and labeled view showing the construction of the Edison cell is shown in Fig. 18-13.

18.22. Care and Management.—The care required by the Edison cell is limited to such matters as the addition of distilled water to replenish electrolyte losses due to electrolysis, and the renewal of the electrolyte when its specific gravity falls below 1.16 at 60°F. after a full charge. The outside of the battery should be kept clean and dry, and the trays and cells given occasional recoating of Esbalite paint.

18.23. The Chemical Reaction in an Edison Cell.—The active material in the positive plate of an Edison cell is an oxide of nickel, and that in the negative plate is pure iron. The electrolyte is an alkaline solution consisting of potassium hydroxide with a small quantity of lithium hydroxide in water.

On discharge the pure iron is oxidized. The oxide of nickel in the positive plates is reduced to a lower oxide. On charge the reverse reaction takes place, the oxide of nickel being raised to a higher oxide and the iron oxide being reduced to pure iron. This transfer of oxygen from the positive to the negative plates on discharge produces electrical energy.

As the potassium hydroxide of the Edison cell electrolyte does not enter into chemical combinations with either the positive or negative active material, the density of the electrolyte does not change appreciably during charge and discharge.

The chemical reactions taking place within an Edison cell on charge and discharge may be indicated as follows:

When Charged

Positive plate is nickel dioxide, NiO_2 .

Negative plate is pure iron, Fe.

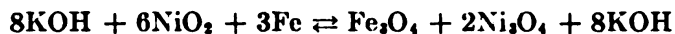
Electrolyte is potassium hydroxide and water, $\text{KOH} + \text{H}_2\text{O}$.

When Discharged

Positive plate is nickel oxide, Ni_2O_3 (partly).

Negative plate is pure iron oxide, Fe_3O_4 .

Electrolyte is potassium hydroxide and water, practically unchanged, $\text{KOH} + \text{H}_2\text{O}$. The chemical formula for charge and discharge is written:



18.24. Charging requires direct current. If only alternating current is available, a suitable motor-generator set or other current-rectifying device must be employed.

When discharged to rated capacity, A, B, and C Edison cells require a $6\frac{1}{4}$ -hr. charge at normal rate to recharge them completely.

If rated capacity has not been used on the previous discharge then the charging period may be correspondingly shortened. A nickel-iron-alkaline storage battery may be considered fully charged when its voltage ceases to rise over a period of about 30 min. during charge with constant current flowing.

The positive and negative sides of the charging line should always be connected to the respective positive and negative battery terminals.

Charging the Edison cell in the wrong direction will cause no damage to the cell as long as the temperature of the electrolyte is not allowed to rise above 115°F . The cell will accumulate a slight charge in the reverse direction. If such a charge should be given accidentally to an Edison battery, the battery should be short-circuited to get rid of the reversed charge by discharge, and then the battery should be charged correctly.

Any one of three charging methods may be used:

1. *Constant-current Method*.—This method requires a line voltage of about 1.85 volts per cell to complete the charge and suitable variable resistance in series with the battery so that the charge may be started at approximately 1.54 volts per cell. As the charge progresses, resistance may be cut out and the current thereby maintained constant. The charging rate of A-, B-, and C-type cells should be maintained at about one-fifth of the rated ampere-hour capacity of the battery.

2. *Modified Constant-potential Method*.—This method requires a line voltage of at least 1.84 volts per cell and a fixed resistance in series with the battery equal to (for A-, B-, and C-type cells): $R = \frac{(\text{line voltage}) - (1.7 \times \text{number of cells})}{\text{normal rate of battery}}$

3. *Trickle-charge Method (Low-rate Continuous Charge)*.—This method requires a line voltage of 1.5 to 1.6 volts per cell. The required rate of charge in amperes for the various sizes of A-, B-, and C-type cells is determined as follows:

$$(\text{Rated amp.-hr. capacity} \times 0.16) + (\text{av. amp.-hr. used per 24 hr.} \times 1.10 \div 24)$$

In an emergency, when the time for a normal charge is not available, charging may be done at higher rates than normal. Electrolyte temperatures should not be allowed to exceed 115°F . in the warmest part of the battery during these high-rate or *boosting* charges as they are sometimes called.

18.25. The state of charge of an Edison battery cannot be determined by hydrometer readings, as there is no change in the specific gravity during charge and discharge. As the voltage of the Edison battery on load when fully charged is 1.37 volts per cell, and as this voltage decreases

to 1.00 volt per cell when discharged, the state of charge may be judged by accurate full-load voltage readings. If the battery installation is fitted with an ampere-hour meter, this meter will indicate directly the state of charge of the battery.

18.26. Ventilation.—As all batteries give off hydrogen gas when gassing, care should be taken to provide sufficient ventilation during charging periods (and also at other times) and to keep away all form of fire or electrical sparking which might serve to ignite the gas and cause explosion.

18.27. Capacity.—The Edison cell maintains its rated capacity throughout the greater part of its long service life. During the early years of life a new cell will actually increase in available capacity as much as 10 per cent. Edison cells are guaranteed for varying numbers of years depending upon the class of service for which they are sold. A useful life of 15 to 20 years and more is not unusual for these batteries in radio service aboard ship.

18.28. Summary of Data on Lead and Edison Cells.

	Edison cell	Lead cell
Voltage { charged.....	1.37	2.10
discharged.....	1.0	1.75
Specific gravity { charged.....	1.220	1.275
discharged.....	1.210	1.150
Charging voltage per cell.....	1.80-2.00	2.30-2.65
Ampere-hour efficiency, per cent.....	80-82	85-95
Watt-hour efficiency, per cent.....	60	72-75

III. STORAGE-BATTERY SWITCHBOARDS AND CHARGERS

In order to arrange conveniently the necessary resistances, switches, circuits, circuit breakers, fuses, meters, and any other apparatus necessary to the operation of the battery installation, a control panel or switchboard is used.

There are many different types of battery panels, each suited to the particular needs of the installation with which it is used. Some of the types of panels found in commercial and broadcasting service will now be explained.

18.29. The Exide switchboard,¹ shown in Figs. 18-14 and 18-15, is widely used on ships and performs the following functions:

¹ Manufactured by the Electric Storage Battery Co., Philadelphia.

1. Connects batteries in series for discharge.
2. Connects battery into two parallel groups for charge.
3. Provides voltmeter for following readings: (a) ship's-line voltage and polarity, batteries on discharge, (c) group A on charge, (d) group B on charge.
4. Opens or closes ship's line, or reverses polarity connection thereto.
5. Provides switches for controlling certain emergency lights.
6. Provides ampere-hour meter to indicate state of battery charge.
7. Provides circuit breaker fitted with overload release, low-voltage release, and automatic trip operated by the ampere-hour meter.

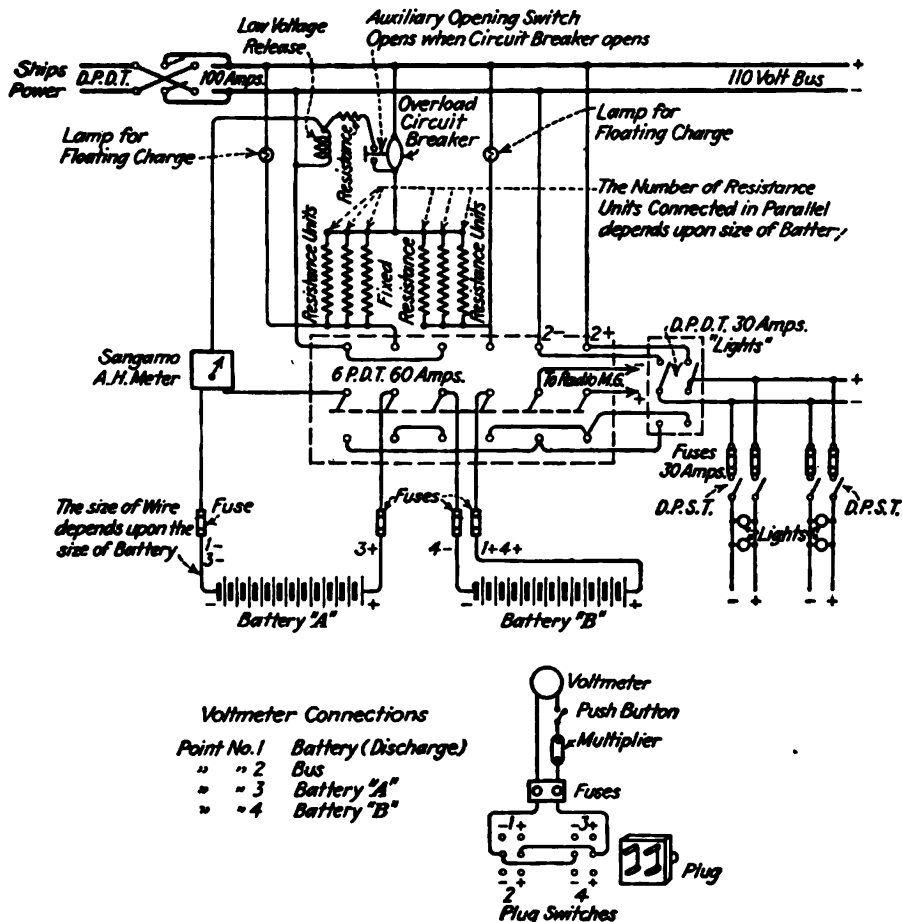


FIG. 18-14.—Schematic diagram of Exide emergency switchboard.

The operation of this switchboard is as follows:

NOTE: In these instructions the following abbreviation is used: 6 PDT = six-pole double throw.

a. Checking Polarity.—First determine that the reversing switch is closed in the proper direction by observing whether the voltmeter reads when the plug switch is in the lower left-hand receptacle which reads the ship's voltage. If it does not read, reverse the reversing switch, then ascertain that the two halves of the battery are also properly connected by taking readings in the upper and lower right-hand receptacles which read "Battery B [and] Battery A and B discharging," respectively.

The voltmeter circuit is normally open, and a push-button switch is provided on the switchboard for closing the circuit when it is desired to take a voltage reading.

This precaution is taken to prevent inductive effects, incidental to the operation of the radio transmitter, from damaging the meter.

b. Charging Battery.—Open the 6 PDT switch. Close the circuit breaker, at the same time holding up the plunger of the low-voltage release coil, and then close the 6 PDT switch to the left. This will place the respective halves of the battery on charge through the charging resistance on the back of the board, which should become uniformly warm. The red pointer on the ampere-hour meter should be set at ampere-hours given in the table of Charging Rates supplied with each installation. The black hand of the ampere-hour meter indicates the state of discharge of the battery

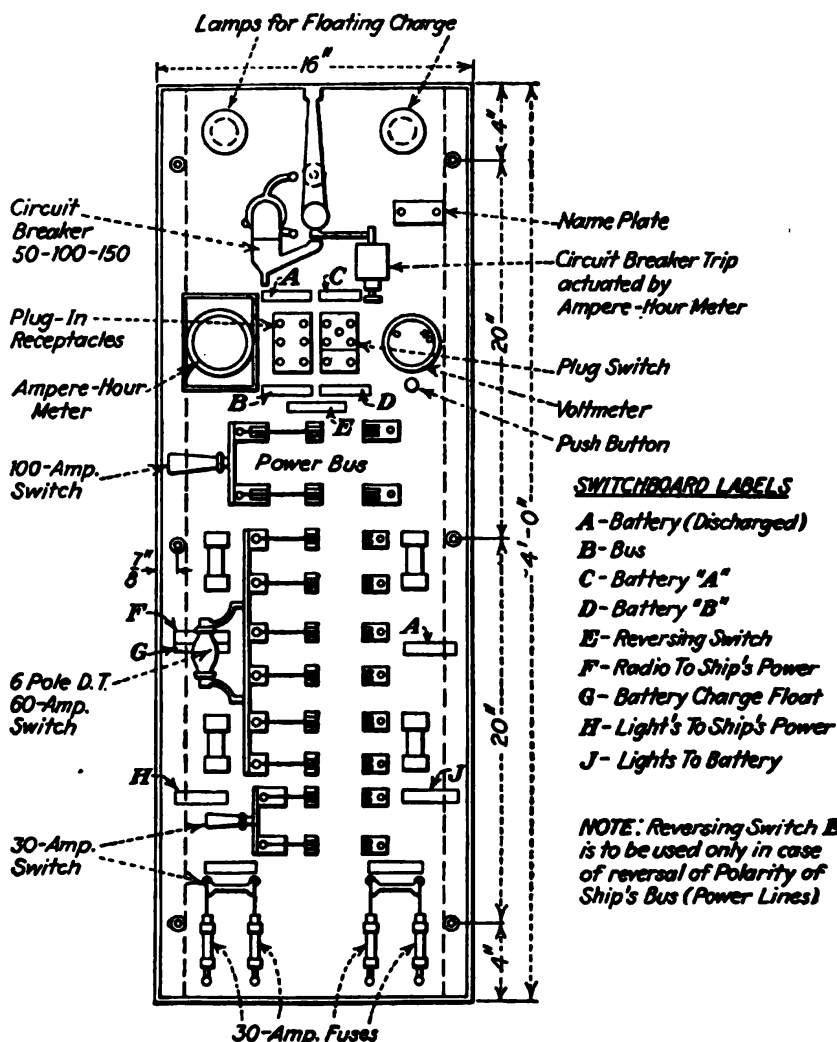


FIG. 18-15.—Front-panel Exide emergency switchboard.

at any time. As soon as the charge is started, the black hand will begin to move toward zero and the charge should be complete when it reaches zero. When the black hand reaches zero it makes a contact which opens the circuit breaker by means of the automatic trip, thus automatically cutting off the charge. For the monthly charge, or if for some other reason the battery requires an overcharge, it is necessary to remove the cover from the ampere-hour meter and turn the black hand back, halfway to the red hand. (The ampere-hour meter should be maintained in good operating condition by being overhauled and recalibrated once every 12 to 18 months.)

If the ship's power circuit fails while the battery is charging, the low-voltage release will open the circuit breaker, preventing the battery from discharging back

into the bus. The battery can be used for supplying current in such an emergency, even though it may not be fully charged.

c. Floating Battery.—With the 6 PDT switch closed to the left and the circuit breaker open, the charging circuit through the resistance units will be open, but the battery will be receiving a floating charge through the two lamps mounted in the upper corners of the switchboard. This is intended to be the normal condition of operation; that is, battery fully charged and floating, with circuit breaker open, and 6 PDT switch closed to the left. With the 6 PDT switch in this position the radio circuit is connected direct to the bus.

When the battery is floating or charging, the lights cannot be operated from it, and the lower double-pole double-throw switch should then be closed to the left. This throws these emergency lights to the ship's line. The feeder switches for the various light circuits can then be opened or closed, as desired.

d. Discharging Battery.—With the circuit breaker open, close the 6 PDT switch to the right. The radio motor generator will now operate from the battery. The emergency lights can also now be operated from the battery, if desired.

e. Ship's Power Off.—Whenever the ship's generator is shut down, care should be taken to open the radio-circuit switch on the ship's switchboard, and all switches on the battery switchboard. Do not burn lights from the battery at such times except for emergency.

18.30. The Edison Battery Switchboard.—This switchboard, shown in Fig. 18-16, is used in connection with marine installations of the Edison

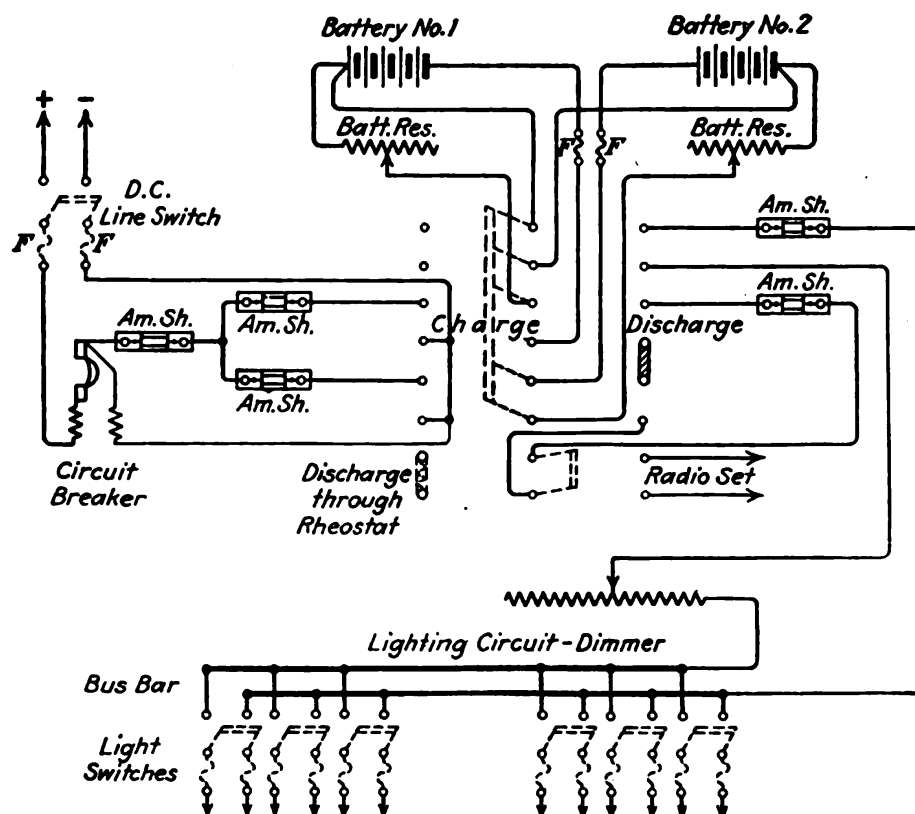


FIG. 18-16.—Schematic diagram of Edison emergency radio switchboard.

battery. Its function is practically the same as that of the Exide switchboard before described, with a few differences, the most important

being the addition of an ammeter on the panel, which may be connected across the various ammeter shunts, shown in the diagram and labeled *Am. Sh.*, by a multi-point selector switch operated by a wheel handle from the front of the panel, and the addition of a heavy-duty rheostat through which the battery may be discharged if it does not get enough action from regular usage.

With new Edison batteries better capacities will result if they are given plenty of work. Likewise, regardless of the age of the battery, sluggishness or low capacity may result from persistent low-rate discharging or charging, or idleness. For best results these batteries must have constant use, and it is for this reason that a special rheostat is provided through which they may be discharged if they are not used regularly in the normal day's work. The procedure is to discharge

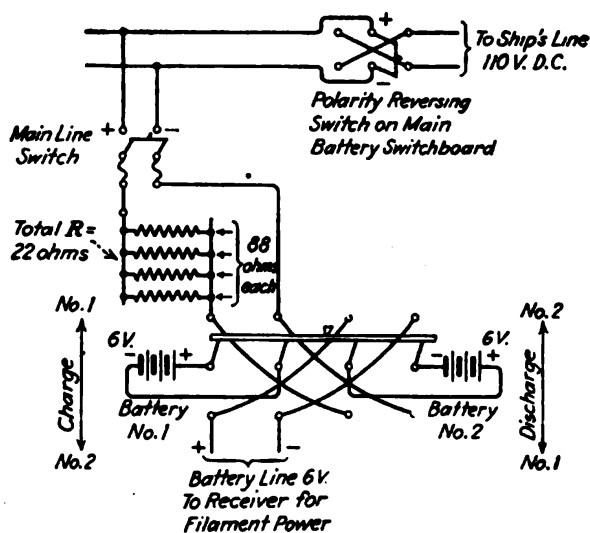


FIG. 18-17.—Schematic diagram of charging panel for receiver batteries, R.M.C.A. type UP-858.

completely the battery through the rheostat to zero and then short-circuit it for 2 hr. Follow this by an overcharge which is a charge at the normal rate for a period in excess of the normal hours of charge. This overcharge period varies from 8 to 15 hr., depending on the type of cell employed.

A voltmeter, fuses, rheostat-adjusting handles, circuit breaker, lighting-circuit dimmer, and the switches shown in the schematic diagram are mounted on the front of the panel. The voltmeter, like the ammeter, is controlled by a multi-point selector switch which gives readings on the ship's line, batteries discharging, batteries 1 or 2 on charge or discharge, and the lighting circuit.

18.31. Charging Panel for Receiver Batteries.—When storage batteries are used for filament supply aboard ship, it is the general practice to provide two batteries so that one may always be available for service while the other one is being charged. A specially designed battery-



FIG. 18-18.—Charging panel, R.M.C.A. type for lifeboat equipment. (Courtesy of R.M.C.A.)

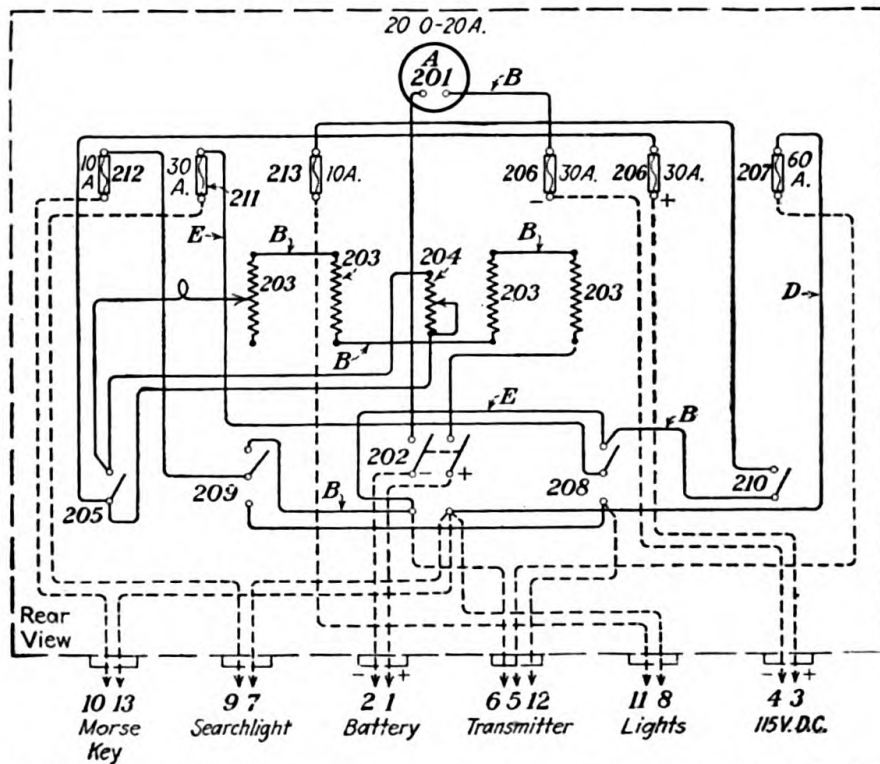


FIG. 18-19.—Schematic diagram of lifeboat battery panel. (Courtesy of R.M.C.A.)

charging panel supplied for this purpose by the R.M.C.A. and known as charging panel type UP-858 is shown schematically in Fig. 18-17. A study of this diagram will make clear how the panel operates. Its installation in the ship's radio room is shown in Fig. 13-21, in Chap. 13 on Marine Radio Transmitters, where the panel is fastened to the bulkhead, to the left of the receiver in the photograph.

18.32. Lifeboat Panel.—A battery charging panel especially designed for use in lifeboat radio equipments and supplied by the R.M.C.A. is shown in Fig. 18-18. A circuit diagram of this panel is shown in Fig. 18-19. The ampere-hour capacity of the battery required depends upon the size of the lighting load added to the radio load. A typical lighting load on a motor-driven lifeboat may consist of one 250-watt searchlight, one 15-watt Morse light, two 15-watt running lights, and two 15-watt inside lights.

Six cells of Exide TL-17 Ironclad storage battery will operate the radio equipment (type ET-3677 transmitter) and all of the above mentioned lights continuously for a period of 6 hr. This battery has a capacity of 66.7 amp. for 6 hr.

18.33. Ampere-hour Meters.—These meters are extensively used with radio-storage-battery installations, not only to indicate the state of charge of the battery, but also to terminate the charge automatically when the battery is fully charged. They measure the product of current and time without regard to voltage and thus provide an accurate means of determining the ampere-hours put into, or taken out of, a battery.

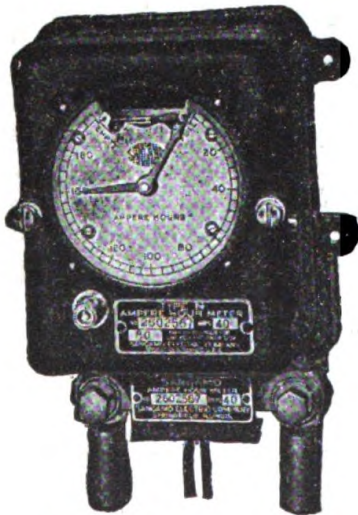


FIG. 18-20.—Ampere-hour meter. (Courtesy of Sangamo Electric Company.)

The most commonly used ampere-hour meter is the Sangamo type N, a view of which is shown in Fig. 18-20. This meter is of the mercury-motor type and comprises a single copper disk rotating in a mercury chamber which is located between the poles of two large permanent magnets. The entire meter is enclosed in a moistureproof steel case which protects it from damage by hard usage. A cross section of the mercury-motor element is shown in Fig. 18-21.

The principles of operation of the mercury-motor type of meter may be explained as follows:

This type of meter employs two permanent magnets between the pole faces of which runs the rotating copper disk as shown in the cross-sectional view in Fig. 18-21. These permanent magnets furnish both the driving flux and damping or retarding force. The shape and size of the magnets are such as to allow a very high magnetiza-

tion. By design the pole tips are close together, being located directly above and below the disk, and produce a very dense and powerful field across the disk. It will be noticed in the cross-sectional view that the current terminal on the left-hand side of the mercury-motor element is labeled as such. A similar current terminal is provided on the opposite side of the motor element, although it is not labeled; instead the current contact ear connecting the current terminal to the mercury is labeled. The arrangement of current terminal and current contact ear is the same on both the right- and left-hand sides of the drawing. The current to be measured flows from one current terminal to the other, passing first through the one side of the body of high-resistance mercury to the copper disk, through the low-resistance copper disk to its opposite side, and thence through the mercury again to the other current terminal.

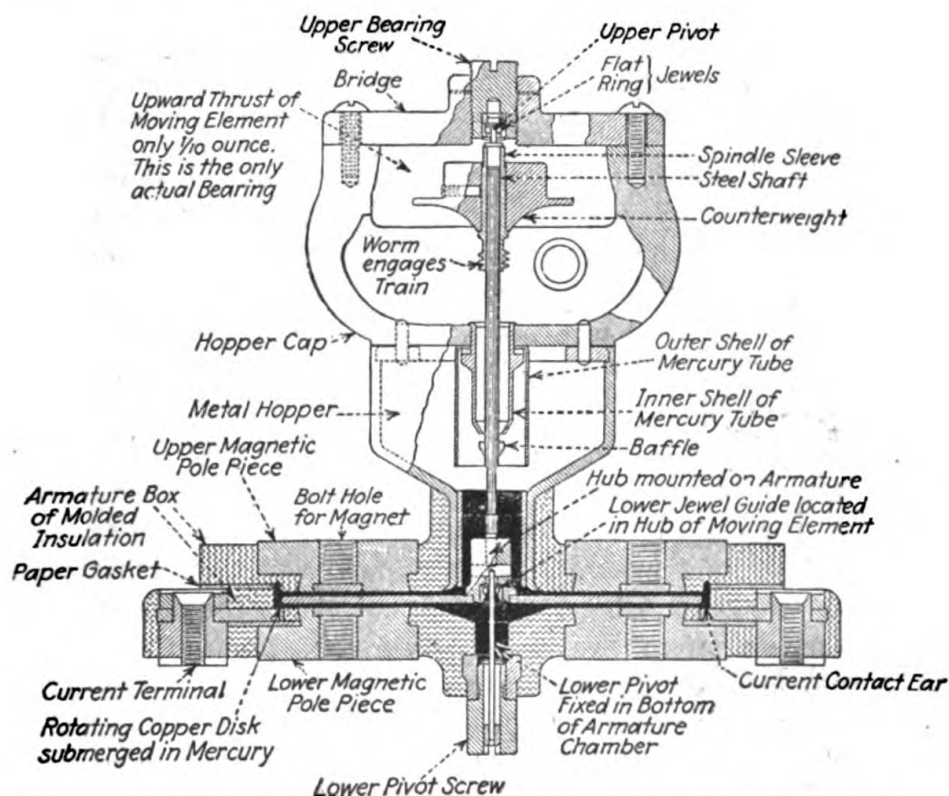


FIG. 18-21.—Mechanism of ampere-hour meter. (Courtesy of Sangamo Electric Company.)

As the current flows through the copper disk it rotates owing to the fundamental action by which a torque is produced when a current flows at right angles through a magnetic field. This torque is directly proportional to the product of the current flowing and the magnetic field produced by the permanent magnets, which in this type meter are very powerful and result in a high torque being produced, insuring accuracy on light loads.

A retarding force must be provided to regulate the speed of the disk, in order to make rotation a measurement of the current. Otherwise, the meter would run at a very high rate of speed and would be erratic owing to the effects of friction. As the disk moves in two powerful magnetic fields, eddy currents are generated, which react with the magnetic flux to produce a damping force proportional to the speed of the disk. With these relations, it is evident that the speed of the meter becomes a measure of the current, and a properly geared indicating mechanism (called a *train*), driven from the main shaft, will therefore register ampere-hours.

Compensating Resistor Element.—No storage battery will give out as much energy as is put into it; therefore, a meter designed to control the charging of storage batteries must automatically provide the required excess of charge over discharge. Moreover, this compensating arrangement should be adjustable over a considerable range since it is seldom that two or more battery installations require the same amount of overcharge, which depends on operating conditions.

The resistor, which automatically provides for the excess of charge over discharge, consists of a small auxiliary mercury chamber located in the leakage field of the permanent magnets. This resistor is connected in series with the armature circuit so that a pivoted copper vane within the chamber changes its position when the current through the armature is reversed. In the discharge position the resistor introduces low resistance in the armature circuit and the meter runs at normal speed. On charge, the position of the vane provides a low-resistance shunt path which the current takes in preference to a path of higher resistance in the armature circuit, thus causing the meter to run at a lower speed. The resistor carries practically all the armature current and is consequently very positive in action. It is not shown in Fig. 18-21.

The state of charge of the battery in ampere-hours is indicated by a hand which revolves over a circular dial. In Fig. 18-20 this hand is shown pointing to the FULL-CHARGE position. In addition to the movable hand, a red hand, which may be set at any desired point on the circular scale to indicate the discharge point at which the batteries are either manually or automatically placed on charge, is provided. When the movable hand reaches the full-charge position, a contact within the meter actuates a circuit breaker which opens the charging circuit. The batteries are thus protected against the damaging effects of an overcharge.

A circuit breaker is usually furnished with the ampere-hour meter which opens the circuit when its coil is energized owing to contact being made in the meter or elsewhere. This circuit breaker is also made in the reverse-current, or no-voltage, release types in which an energized coil keeps the armature holding the contacts in the closed position so long as there is correct voltage on the charging line.

18.34. Reverse-current Relay.—On a battery-charging circuit where the charging voltage applied to the battery terminals is that of the charging generator (no series-charging resistors used), it is necessary to provide a reverse-current relay, or cutout, which will open the charging circuit under the following conditions: (a) when the battery voltage equals or nears the generator voltage at the end of a charge, (b) if the voltage of the generator should fall below the required charging value before the charge is completed, (c) if the polarity of the charging voltage is incorrect.

A reverse-current relay, Fig. 18-22, consists of a solenoid electromagnet which acts on a movable armature carrying a contact that opens or closes the charging circuit to the battery.

The electromagnet on the reverse-current relay consists of an iron core over which are wound two coils, a shunt coil of many turns of fine wire, and a series coil of a much smaller number of turns of heavy wire.

The shunt coil, as its name implies, is connected in shunt to the charging circuit and acts as a holding coil to hold the contact-carrying armature closed while the battery is charging. If the circuit is provided with an ampere-hour meter, this holding coil, if operated on low voltage through a series resistor, could be short-

circuited through an auxiliary contact in the ampere-hour meter when the battery is fully charged. As soon as the holding coil was short-circuited, the armature of the relay would drop down, the contacts would open, and the batteries would be off the line.

The series coil, as its name implies, is connected in series with one side of the charging line and is so arranged that when current is flowing into the battery the field of the series coil assists or augments the field of the shunt-holding coil in keeping the armature in the contacts-closed position.

If for any reason the battery begins to discharge back into the generator, resulting in a reverse current in the series coil, the field produced by this coil will buck or neutralize the field of the shunt-holding coil. This would cause the armature to drop away from the core and the contacts to open, thus opening the charging circuit.

If the mechanical arrangement of the armature is such that the force of gravity will not pull the armature away from the core when the magnetization of the core is nullified, a spring must be arranged to perform this operation.

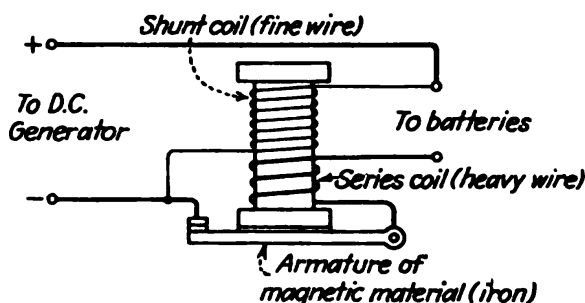


FIG. 18-22.—Reverse-current relay.

18.35. The Tungar battery charger as developed and manufactured by the General Electric Company is a device for charging storage batteries from an alternating-current line, and it acts as a rectifier and current-limiting device.

The Tungar bulb follows the general principles of operation of the two-element vacuum tube in which a unidirectional electronic flow takes place between the hot cathode and a cold anode. In the bulb there is an inert (argon) gas at low pressure, which is ionized by the electrons emitted by the hot cathode, and which acts as the principal current carrier. The result is that the bulb operates with a very low voltage drop (6 to 8 volts) and is capable of passing a current of several amperes, the current limit depending on the size of the bulb.

The half-wave bulb consists of a cathode of small tungsten wire coiled into a closely wound spiral to form the filament. The anode is made of graphite and has a relatively large cross section. The bulbs are constructed of high-heat-resisting glass.

The action of the vacuum tube as a rectifier has already been explained in the section of Rectifiers in Sec. 6.5. The Tungar bulb follows this principle of action, being similar to the mercury-vapor tube in its ionization properties.

All Tungar bulbs are carefully exhausted to the highest possible vacuum and then filled with argon gas in a high state of purity. Certain

impurities however, even though present in very small quantities, produce a more or less rapid disintegration of the cathode and also have quite a marked effect on the voltage characteristics of the rectifier. Means must be used to insure absolute purity of the gas from these foreign gases and, to accomplish this, magnesium is introduced into the bulb at the time of manufacture, to react chemically with such impurities as may be present. This reaction keeps the gas in a pure state practically throughout the life of the bulb.

The dark gray or silvery appearance of the bulb is caused by condensation of the purifying agent, magnesium, on the interior of the bulb during manufacture. This is not in the least detrimental to the bulb and does not give any indication of the life of the bulb.

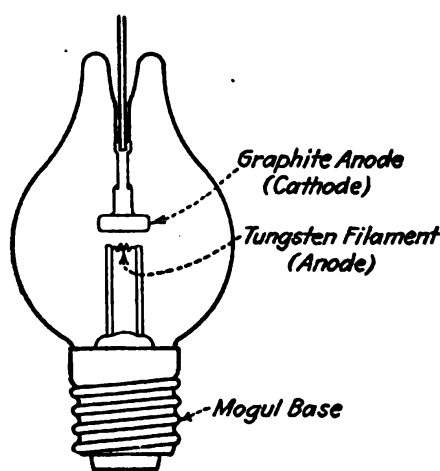


FIG. 18-23.—Tungar rectifier bulb.

One of the larger sized Tungar bulbs is shown in Fig. 18-23. This bulb handles 6 amp. of direct current at a pressure of 60 volts. The recommended filament voltage is 2.2 volts and the approximate filament current 18 amp. It has a maximum inverse-peak voltage of 300 volts. While it is possible to make a Tungar bulb containing two plates for full-wave rectification with one bulb, all, except a small full-wave bulb having a capacity of $\frac{1}{2}$ amp., are of the half-wave type with one anode. Full-wave rectification can, of course, be obtained by means of two half-wave bulbs connected to a transformer with a split secondary. Full- and half-wave rectifier circuits are shown in Chap. 6 on Electronic Power Supplies and will not be repeated here.

When two half-wave rectifiers are operating from the same supply circuit, it is desirable to reverse the primary connections of one of the outfits, that is, arrange the alternating-current connections so that one outfit operates during one half of the cycle and the other outfit during the second half of the cycle. The effect of this is a considerable increase in the power factor of the circuit.

With rectifiers equipped with insulating transformers it is possible to connect the direct-current terminals to the same load and obtain full-wave rectification. The primaries must, of course, be reversed as described in the preceding paragraph.

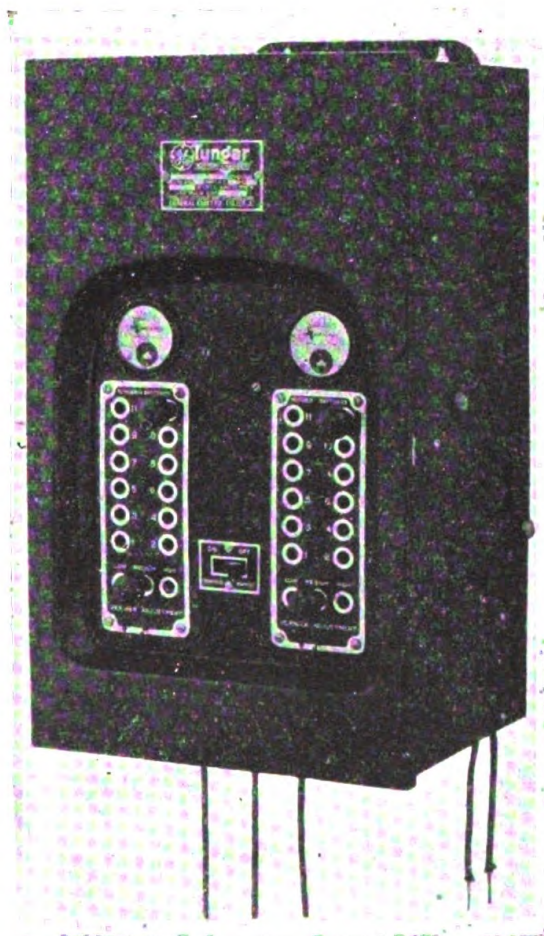


FIG. 18-24.—Heavy-duty Tungar charger. (Courtesy of General Electric Company.)

A type of Tungar rectifier used in broadcasting stations is shown in Fig. 18-24. This is a full-wave charger utilizing two bulbs and designed to charge 24 three-cell lead-storage batteries at 6 amp. or 12 similar batteries at 12 amp.

APPENDIX

USEFUL TECHNICAL AND OPERATING INFORMATION

TABLE A.—WAVE-LENGTH-FREQUENCY CONVERSION TABLE (VERY HIGH AND ULTRA HIGH FREQUENCIES)

λ		mc./s.	λ m.	mc./s.	λ m.	mc./s.
cm.	m.					
10	0.1	3,000	4.1	73.1	8.1	37.0
20	0.2	1,500	4.2	71.4	8.2	36.6
30	0.3	1,000	4.3	69.7	8.3	36.1
40	0.4	745	4.4	68.1	8.4	35.7
50	0.5	600	4.5	66.6	8.5	35.3
60	0.6	500	4.6	65.2	8.6	34.7
70	0.7	429	4.7	63.8	8.7	34.5
80	0.8	375	4.8	62.5	8.8	34.1
90	0.9	333	4.9	61.2	8.9	33.7
	1.0	300	5.0	60.0	9.0	33.3
	1.1	273	5.1	58.8	9.1	33.0
	1.2	250	5.2	57.7	9.2	32.6
	1.3	231	5.3	56.6	9.3	32.2
	1.4	214	5.4	55.5	9.4	31.9
	1.5	200	5.5	54.5	9.5	31.6
	1.6	187	5.6	53.5	9.6	31.2
	1.7	176	5.7	52.6	9.7	31.0
	1.8	167	5.8	51.7	9.8	30.4
	1.9	158	5.9	50.8	9.9	30.1
	2.0	150	6.0	50.0	10.0	30.0
	2.1	143	6.1	49.2	10.1	29.7
	2.2	136	6.2	48.4	10.2	29.4
	2.3	130	6.3	47.6	10.3	29.1
	2.4	125	6.4	46.9	10.4	28.8
	2.5	120	6.5	46.1	10.5	28.6
	2.6	115	6.6	45.4	10.6	28.3
	2.7	111	6.7	44.8	10.7	28.0
	2.8	107	6.8	44.1	10.8	27.8
	2.9	103	6.9	43.5	10.9	27.5
	3.0	100	7.0	42.9	11.0	27.3
	3.1	96.7	7.1	42.2	11.1	27.0
	3.2	93.7	7.2	41.6	11.2	26.8
	3.3	90.9	7.3	41.1	11.3	26.5
	3.4	88.2	7.4	40.5	11.4	26.3
	3.5	85.7	7.5	40.0	11.5	26.1
	3.6	83.3	7.6	39.5	11.6	25.9
	3.7	81.0	7.7	38.9	11.7	25.6
	3.8	78.9	7.8	38.4	11.8	25.4
	3.9	76.9	7.9	38.0	11.9	25.2
	4.0	75.0	8.0	37.5	12.0	25.0

NOTE: cm. = centimeters; m. = meters; mc/s. = megacycles.

TABLE B.—RELATION OF WAVE LENGTH (λ), FREQUENCY (f), $2\pi f = (\omega)$, AND $L \times C$ (Reprinted from "The Principles Underlying Radio Communication" by permission of the War Department, Office of the Chief Signal Officer)

λ = wave length in meters.

f = frequency, cycles per second. (Multiply values in table by 1,000.)

$\omega = 2\pi$ times the frequency ($= 6.28f$). (Multiply values in table by 1,000.)

L = inductance in centimeters. (1,000 cm. of inductance = 1 microhenry).

C = capacity in microfarads.

Example 1: Find the capacity which must be connected in series with an inductance of 500,000 cm. (500 μ h.) in order to tune to 2,500 meters. In the table opposite 2,500 meters we find for LC a value of 1,760, which divided by 500,000 yields a quotient of 0.00352. The capacity which must be used is, therefore, 0.00352 mf.

Example 2: What inductance must be placed in series with a condenser of 0.005 mf. in order that the circuit may have a wave length of 600 meters? In the table opposite 600 meters we find for LC a value of 101.4, which divided by 0.005 yields a quotient of 20,280. The inductance which must be used is, therefore, 20,280 cm., or 20.28 μ h.

Example 3: Find the wave length of a circuit having a capacity of 0.0001 mf., and an inductance of 101,600 cm. (101.6 μ h.). The product of the inductance and the capacity is $101,600 \times 0.0001 = 10.16$. In the column headed LC we find that a value of $LC = 10.16$ corresponds to a wave length of 190 meters.

λ Wave length, meters	f Multiply values below by 1,000	ω Multiply values below by 1,000	LC L in cm. C in μ f.	λ Wave length, meters	f Multiply values below by 1,000	ω Multiply values below by 1,000	LC L in cm.* C in μ f.
1	300,000	1,884,000	0.0003	100	3,000	18,840	2.816
2	150,000	942,000	0.0011	105	2,857	17,940	3.105
3	100,000	628,000	0.0018	110	2,727	17,130	3.404
4	75,000	471,000	0.0045	115	2,609	16,380	3.721
5	60,000	377,000	0.0057	120	2,500	15,710	4.05
6	50,000	314,200	0.0101	125	2,400	15,070	4.40
7	42,900	269,000	0.0138	130	2,308	14,480	4.76
8	37,500	235,500	0.0180	135	2,222	13,950	5.13
9	33,330	209,400	0.0228	140	2,144	13,450	5.52
10	30,000	188,400	0.0282	145	2,069	12,980	5.92
15	20,000	125,600	0.0635	150	2,000	12,560	6.34
20	15,000	94,200	0.1129	155	1,935	12,150	6.76
25	12,000	75,400	0.1755	160	1,875	11,770	7.20
30	10,000	62,800	0.2530	165	1,818	11,410	7.66
35	8,570	53,800	0.3446	170	1,765	11,080	8.13
40	7,500	47,100	0.450	175	1,714	10,760	8.62
45	6,670	41,900	0.570	180	1,667	10,470	9.12
50	6,000	37,700	0.704	185	1,622	10,180	9.63
55	5,450	34,220	0.852	190	1,579	9,910	10.16
60	5,000	31,420	1.014	195	1,538	9,660	10.71
65	4,620	28,970	1.188				
70	4,290	26,900	1.378	200	1,500	9,420	11.26
75	4,000	25,120	1.583	205	1,463	9,190	11.83
80	3,750	23,520	1.801	210	1,429	8,970	12.41
85	3,529	22,120	2.034	215	1,395	8,760	13.01
90	3,333	20,920	2.280	220	1,364	8,560	13.62
95	3,158	19,830	2.541	225	1,333	8,370	14.25

* If L is in microhenrys, divide the value in the column by 1,000; if in henrys, divide by 10⁹.

TABLE B.—RELATION OF WAVE LENGTH (λ), FREQUENCY (f), $2\pi f = (\omega)$, AND $L \times C$.
(Continued)

λ Wave length, meters	f Multiply values below by 1,000	ω Multiply values below by 1,000	LC L in cm. C in μf .	λ Wave length, meters	f Multiply values below by 1,000	ω Multiply values below by 1,000	LC L in cm. C in μf .
230	1,304	8,190	14.89	640	469	2,942	115.4
235	1,277	8,020	15.55	650	462	2,896	118.8
240	1,250	7,850	16.22	660	455	2,852	122.5
245	1,225	7,680	16.90	670	448	2,810	126.3
				680	441	2,768	130.2
250	1,200	7,540	17.60	690	435	2,730	134.1
255	1,177	7,390	18.31				
260	1,154	7,250	19.03	700	429	2,692	137.8
265	1,132	7,110	19.77	710	423	2,654	141.9
270	1,111	6,980	20.52	720	417	2,616	145.9
275	1,091	6,860	21.29	730	411	2,580	150.0
280	1,071	6,740	22.07	740	405	2,544	154.0
285	1,053	6,620	22.87	750	400	2,510	158.3
290	1,035	6,500	23.66	760	394.8	2,476	162.6
295	1,017	6,380	24.50	770	389.6	2,443	166.8
				780	384.6	2,412	171.4
300	1,000	6,280	25.33	790	379.8	2,382	175.6
310	968	6,080	27.05				
320	938	5,890	28.83	800	375.0	2,353	180.1
330	909	5,700	30.66	810	370.4	2,325	184.7
340	882	5,540	32.55	820	365.9	2,297	189.3
350	857	5,380	34.48	830	361.4	2,270	194.0
360	833	5,230	36.48	840	357.1	2,242	198.5
370	811	5,090	38.54	850	352.9	2,214	203.4
380	790	4,963	40.7	860	348.8	2,188	208.2
390	769	4,830	42.8	870	344.8	2,162	213.2
				880	340.9	2,138	217.9
400	750	4,710	45.0	890	337.1	2,115	222.9
410	732	4,590	47.3				
420	714	4,480	49.7	900	333.3	2,092	228.0
430	698	4,380	52.0	910	329.7	2,070	233.2
440	682	4,280	54.5	920	326.1	2,047	238.1
450	667	4,190	57.0	930	322.6	2,024	243.4
460	652	4,100	59.6	940	319.1	2,003	248.7
470	638	4,010	62.3	950	315.8	1,982	254.1
480	625	3,920	64.8	960	312.5	1,962	259.5
490	612	3,842	67.6	970	309.3	1,942	264.7
				980	306.1	1,922	270.4
500	600	3,766	70.4	990	303.0	1,902	275.9
510	588	3,692	73.3				
520	577	3,620	76.0	1,000	300.0	1,884	281.6
530	566	3,552	79.0	1,050	285.7	1,794	310.5
540	556	3,485	82.1	1,100	272.7	1,712	340.4
550	545	3,422	85.2	1,150	260.9	1,637	372.1
560	536	3,361	88.4	1,200	250.0	1,570	405
570	526	3,302	91.4	1,250	240.0	1,506	440
580	517	3,246	94.7	1,300	230.8	1,448	476
590	509	3,193	98.0	1,350	222.2	1,395	513
				1,400	214.4	1,346	552
600	500	3,140	101.4	1,450	206.9	1,298	592
610	492	3,088	104.7				
620	484	3,038	108.2	1,500	200.0	1,256	634
630	476	2,990	111.7	1,550	193.5	1,215	676

TABLE B.—RELATION OF WAVE LENGTH (λ), FREQUENCY (f), $2\pi f = (\omega)$, AND $L \times C$.
(Concluded)

λ Wave length, meters	f Multiply values below by 1,000	ω Multiply values below by 1,000	LC L in cm. C in $\mu f.$	λ Wave length, meters	f Multiply values below by 1,000	ω Multiply values below by 1,000	LC L in cm. C in $\mu f.$
1,600	187.5	1,177	720	2,900	103.5	648	2,366
1,650	181.8	1,142	766	2,950	101.7	638	2,450
1,700	176.5	1,108	813				
1,750	171.4	1,076	862	3,000	100.0	628	2,533
1,800	166.7	1,046	912	3,500	85.7	538	3,448
1,850	162.2	1,017	963	4,000	75.0	471	4,500
1,900	157.9	990	1,016	4,500	66.7	418	5,700
1,950	153.8	965	1,071	5,000	60.0	377	7,040
				5,500	54.5	342.2	8,520
2,000	150.0	942	1,126	6,000	50.0	314.2	10,140
2,050	146.3	920	1,183	6,500	46.2	289.8	11,880
2,100	142.9	898	1,241	7,000	42.9	268.8	13,780
2,150	139.5	876	1,301	7,500	40.0	251.0	15,830
2,200	136.4	856	1,362				
2,250	133.3	838	1,425	8,000	37.50	235.2	18,010
2,300	130.4	819	1,489	8,500	35.29	221.4	20,340
2,350	127.7	801	1,555	9,000	33.33	209.2	22,800
2,400	125.0	784	1,622	9,500	31.58	198.2	25,410
2,450	122.5	768	1,690	10,000	30.00	188.4	28,160
				15,000	20.00	125.7	63,400
2,500	120.0	753	1,760	20,000	15.00	94.2	112,600
2,550	117.7	738	1,831	25,000	12.00	75.4	176,000
2,600	115.4	724	1,903	30,000	10.00	62.8	253,300
2,650	113.2	710	1,977	35,000	8.57	53.8	344,800
2,700	111.1	697	2,052				
2,750	109.1	684	2,129	40,000	7.50	47.1	450,000
2,800	107.1	672	2,207	45,000	6.67	41.8	570,000
2,850	105.3	660	2,287	50,000	6.00	37.7	704,000

THREE-PLACE LOGARITHMIC TABLES

Complete Logarithms of Numbers 1 to 100

N.	log	N.	log	N.	log	N.	log	N.	log
1	0.000	21	1.322	41	1.613	61	1.785	81	1.908
2	0.301	22	1.342	42	1.623	62	1.792	82	1.914
3	0.477	23	1.362	43	1.633	63	1.799	83	1.919
4	0.602	24	1.380	44	1.643	64	1.806	84	1.924
5	0.699	25	1.397	45	1.653	65	1.813	85	1.929
6	0.778	26	1.415	46	1.663	66	1.820	86	1.934
7	0.845	27	1.431	47	1.672	67	1.826	87	1.940
8	0.903	28	1.447	48	1.681	68	1.833	88	1.944
9	0.954	29	1.462	49	1.690	69	1.839	89	1.949
10	1.000	30	1.477	50	1.699	70	1.845	90	1.954
11	1.041	31	1.491	51	1.708	71	1.851	91	1.959
12	1.079	32	1.505	52	1.716	72	1.857	92	1.964
13	1.114	33	1.518	53	1.724	73	1.863	93	1.968
14	1.146	34	1.531	54	1.732	74	1.869	94	1.973
15	1.176	35	1.544	55	1.740	75	1.875	95	1.978
16	1.204	36	1.556	56	1.748	76	1.881	96	1.982
17	1.230	37	1.568	57	1.756	77	1.886	97	1.987
18	1.255	38	1.580	58	1.763	78	1.892	98	1.991
19	1.279	39	1.591	59	1.771	79	1.898	99	1.996
20	1.301	40	1.602	60	1.778	80	1.903	100	2.000

Mantissas of Numbers 1 to 2,009

N.	0	1	2	3	4	5	6	7	8	9
10	000	004	009	013	017	021	025	029	033	037
11	041	045	050	053	057	061	064	068	072	076
12	079	083	086	090	093	097	100	104	107	111
13	114	117	121	124	127	130	134	137	140	143
14	146	149	152	155	158	161	164	167	170	173
15	176	179	182	185	188	190	193	196	199	201
16	204	207	210	212	215	217	220	223	225	228
17	230	233	236	238	241	243	246	248	250	253
18	255	258	260	262	265	267	270	272	274	276
19	279	281	283	286	288	290	292	294	297	299
20	301	303	305	307	310	312	314	316	318	320
21	322	324	326	328	330	332	334	336	338	340
22	342	344	346	348	350	352	354	356	358	360
23	362	364	365	367	369	371	373	375	377	378
24	380	382	384	386	387	389	391	393	394	396
25	398	400	401	403	405	407	408	410	412	413
26	415	417	418	420	422	423	425	427	428	430
27	431	433	435	436	438	439	441	442	444	446
28	447	449	450	452	453	455	456	458	459	461
29	462	464	465	467	468	470	471	473	474	476
30	477	479	480	481	483	484	486	487	489	490
31	491	493	494	496	497	498	500	501	502	504
32	505	507	508	509	511	512	513	515	516	517
33	519	520	521	522	524	525	526	528	529	530
34	531	533	534	535	537	538	539	540	542	543
35	544	545	547	548	549	550	551	553	554	555
36	556	558	559	560	561	562	563	565	566	567
37	568	569	571	572	573	574	575	576	577	579
38	580	581	582	583	584	585	587	588	589	590
39	591	592	593	594	595	597	598	599	600	601
40	602	603	604	605	606	607	609	610	611	612
41	613	614	615	616	617	618	619	620	621	622
42	623	624	625	626	627	628	629	630	631	632
43	633	634	635	636	637	638	639	640	641	642
44	643	644	645	646	647	648	649	650	651	652
45	653	654	655	656	657	658	659	660	661	662
46	663	664	665	666	667	667	668	669	670	671
47	672	673	674	675	676	677	678	679	679	680
48	681	682	683	684	685	686	687	688	688	689
49	690	691	692	693	694	695	695	696	697	698

Mantiseas of Numbers 1 to 2,009

N.	0	1	2	3	4	5	6	7	8	9
50	699	700	701	702	702	703	704	705	706	707
51	708	708	709	710	711	712	713	713	714	715
52	716	717	718	719	719	720	721	722	723	723
53	724	725	726	727	728	728	729	730	731	732
54	732	733	734	735	736	736	737	738	739	740
55	740	741	742	743	744	744	745	746	747	747
56	748	749	750	751	751	752	753	754	754	755
57	756	757	757	758	759	760	760	761	762	763
58	763	764	765	766	766	767	768	769	769	770
59	771	772	772	773	774	775	775	776	777	777
60	778	779	780	780	781	782	782	783	784	785
61	785	786	787	787	788	789	790	790	791	792
62	792	793	794	794	795	796	797	797	798	799
63	799	800	801	801	802	803	803	804	805	806
64	806	807	808	808	809	810	810	811	812	812
65	813	814	814	815	816	816	817	818	818	819
66	820	820	821	822	823	823	824	824	825	825
67	826	827	827	828	829	829	830	831	831	832
68	833	833	834	834	835	836	836	837	838	838
69	839	839	840	841	841	842	843	843	844	844
70	845	846	846	847	848	848	849	849	850	851
71	851	852	852	853	854	854	855	856	856	857
72	857	858	859	859	860	860	861	862	862	863
73	863	864	865	865	866	866	867	867	868	869
74	869	870	870	871	872	872	873	873	874	874
75	875	876	876	877	877	878	879	879	880	880
76	881	881	882	883	883	884	884	885	885	886
77	886	887	888	888	889	889	890	890	891	892
78	892	893	893	894	894	895	895	896	897	897
79	898	898	899	899	900	900	901	901	902	903
80	903	904	904	905	905	906	906	907	907	908
81	908	909	910	910	911	911	912	912	913	913
82	914	914	915	915	916	916	917	918	918	919
83	919	920	920	921	921	922	922	923	923	924
84	924	925	925	926	926	927	927	928	928	929
85	929	930	930	931	931	932	932	933	933	934
86	934	935	936	936	937	937	938	938	939	939
87	940	940	941	941	942	942	943	943	943	944
88	944	945	945	946	946	947	947	948	948	949
89	949	950	950	951	951	952	952	953	953	954
90	954	955	955	956	956	957	957	958	958	959
91	959	960	960	960	961	961	962	962	963	963
92	964	964	965	965	966	966	967	967	968	968
93	968	969	969	970	970	971	971	972	972	973
94	973	974	974	975	975	975	976	976	977	977
95	978	978	979	979	980	980	980	981	981	982
96	982	983	983	984	984	985	985	985	986	986
97	987	987	988	988	989	989	989	990	990	991
98	991	992	992	993	993	993	994	994	995	995
99	996	996	997	997	997	998	998	999	999	000
100	000	000	001	001	002	002	003	003	003	004
101	004	005	005	006	006	006	007	007	008	008
102	009	009	009	010	010	011	011	012	012	012
103	013	013	014	014	015	015	015	016	016	017
104	017	017	018	018	019	019	020	020	020	021
105	021	022	022	022	023	023	024	024	024	025
106	025	026	026	027	027	027	028	028	029	029
107	029	030	030	031	031	031	032	032	033	033
108	033	034	034	035	035	035	036	036	037	037
109	037	038	038	039	039	039	040	040	041	041
110	041	042	042	043	043	043	044	044	045	045
111	045	046	046	046	047	047	048	048	048	049
112	049	050	050	050	051	051	052	052	052	053
113	053	053	054	054	055	055	055	056	056	057
114	057	057	058	058	058	059	059	060	060	060
115	061	061	061	062	062	063	063	063	064	064
116	064	065	065	066	066	066	067	067	067	068
117	068	069	069	069	070	070	070	071	071	072
118	072	072	073	073	073	074	074	074	075	075
119	076	076	076	077	077	077	078	078	078	079
120	079	080	080	080	081	081	081	082	082	082
121	083	083	084	084	084	085	085	085	086	086
122	086	087	087	087	088	088	088	089	089	090
123	090	090	091	091	091	092	092	092	093	093
124	093	094	094	094	095	095	096	096	096	097

Mantissas of Numbers 1 to 2,009

N.	0	1	2	3	4	5	6	7	8	9
125	097	097	098	098	098	099	099	099	100	100
126	100	101	101	101	102	102	102	103	103	103
127	104	104	104	105	105	106	106	106	107	107
128	107	108	108	108	109	109	109	110	110	110
129	111	111	111	112	112	112	113	113	113	114
130	114	114	115	115	115	116	116	116	117	117
131	117	118	118	118	119	119	119	120	120	120
132	121	121	121	122	122	122	123	123	123	124
133	124	124	125	125	125	125	126	126	126	127
134	127	127	128	128	128	129	129	129	130	130
135	130	131	131	131	132	132	132	133	133	133
136	134	134	134	134	135	135	135	136	136	136
137	137	137	137	138	138	138	139	139	139	140
138	140	140	141	141	141	141	142	142	142	142
139	143	143	144	144	144	145	145	145	146	146
140	146	146	147	147	147	148	148	148	149	149
141	149	150	150	150	150	151	151	151	152	152
142	152	153	153	153	154	154	154	154	155	155
143	155	156	156	156	157	157	157	157	158	158
144	158	159	159	159	160	160	160	160	161	161
145	161	162	162	162	163	163	163	163	164	164
146	164	165	165	165	166	166	166	166	167	167
147	167	168	168	168	168	169	169	169	170	170
148	170	171	171	171	171	172	172	172	173	173
149	173	173	174	174	174	175	175	175	176	176
150	176	176	177	177	177	178	178	178	178	179
151	179	179	180	180	180	181	181	181	181	182
152	182	182	182	183	183	183	184	184	184	184
153	185	185	185	186	186	186	186	187	187	187
154	188	188	188	188	189	189	189	189	190	190
155	190	191	191	191	191	192	192	192	193	193
156	193	193	194	194	194	195	195	195	195	196
157	196	196	196	197	197	197	198	198	198	198
158	199	199	199	199	200	200	200	201	201	201
159	201	202	202	202	202	203	203	203	204	204
160	204	204	205	205	205	205	206	206	206	207
161	207	207	207	208	208	208	208	209	209	209
162	210	210	210	210	211	211	211	211	212	212
163	212	212	213	213	213	214	214	214	214	215
164	215	215	215	216	216	216	216	217	217	217
165	217	218	218	218	219	219	219	219	220	220
166	220	220	221	221	221	222	222	222	222	222
167	223	223	223	223	224	224	224	225	225	225
168	225	226	226	226	226	227	227	227	227	228
169	228	228	228	229	229	229	229	230	230	230
170	230	231	231	231	231	232	232	232	232	233
171	233	233	234	234	234	234	235	235	235	235
172	236	236	236	236	237	237	237	237	238	238
173	238	238	239	239	239	239	240	240	240	240
174	241	241	241	241	242	242	242	242	243	243
175	243	243	244	244	244	244	245	245	245	245
176	246	246	246	246	246	247	247	247	247	248
177	248	248	248	249	249	249	249	250	250	250
178	250	251	251	251	251	252	252	252	252	253
179	253	253	253	254	254	254	254	255	255	255
180	255	256	256	256	256	256	257	257	257	257
181	258	258	258	258	259	259	259	259	260	260
182	260	260	261	261	261	261	262	262	262	262
183	262	263	263	263	263	264	264	264	264	265
184	265	265	265	266	266	266	266	266	267	267
185	267	267	268	268	268	268	269	269	269	269
186	270	270	270	270	270	271	271	271	271	272
187	272	272	272	273	273	273	273	273	274	274
188	274	274	275	275	275	275	276	276	276	276
189	276	277	277	277	277	278	278	278	278	279
190	279	279	279	279	280	280	280	280	281	281
191	281	281	281	282	282	282	282	283	283	283
192	283	284	284	284	284	284	285	285	285	285
193	286	286	286	286	286	287	287	287	287	288
194	288	288	288	288	289	289	289	289	290	290
195	290	290	290	291	291	291	291	292	292	292
196	292	292	293	293	293	293	294	294	294	294
197	294	295	295	295	295	296	296	296	296	296
198	297	297	297	297	298	298	298	298	298	299
199	299	299	299	300	300	300	300	300	301	301
200	301	301	301	302	302	302	302	303	303	303

INDEX

A

A1 emission, 652, 684, 687, 720, 737
A2 emission, 650-653, 684, 686, 688, 720, 737
AVC (*see* Automatic volume control)
Absolute zero temperature, 11
Absorption coefficient, 501-502
Acceptor circuits, 237-238, 244
Accessories, 753
Acoustical feedback, 555
Acoustics, 500-504
Adcock antenna, 378-379, 483-484
Adjunct mixing, 553-554
Admittance, 95-97
Aircraft antennas, 450-451, 472-476
Aircraft direction finders, 489-499
Aircraft radio (*see* Aviation radio)
Aircraft shielding and bonding, 476-479
Aligning procedure, 283-285
Alternating current, generation of, 60-62
 principles of, 60-104
 sine wave of, 84, 85
Alternating-current generators (*see* Alternators)
Alternators, inductor type, 819, 820
 principle of, 60-62
 revolving field type, 101
 three-phase, 101-104
 types of, 818-820
 voltage control on, 821
Ammeter, 332-334, 336-339
Ampere, 10
Ampere-hour capacity, 35
Ampere-hour meter, 900-902
Ampere turns, 55
Amplification factor, 111-113
Amplifier calculations, 510-515
Amplifiers, 116-122, 213-230
 audio-frequency, 215-230, 604, 605
 booster, 584
 broadcast, 561
 buffer, 162, 163
 Class A, 120
 Class AB, 121

Amplifiers, Class B, 121, 122
 Class C, 123
 design of, in transmitters, 162-167, 172-183
 distortion in (*see* Distortion)
 efficiency of, 120, 183, 188
 frequency-doubling, 165-167
 hum in, 113-115
 impedance coupled, 218, 219
 intermediate-frequency, 248-250, 421-425
 limiting, 545
 linear, 122, 164, 176, 210, 212, 213
 low-gain, 560, 561
 monitor, 578
 output impedance adjustment on, 176-178
 power (*see* Power amplifier)
 pre-amplifier, 520
 push-pull, 122, 124, 223-228
 radio-frequency, 116-122, 602-618
 resistance-coupled, 217, 218
 response characteristic, 723
 speech, 545, 546
 transformer-coupled, 215-217
 audio, troubles with, 723, 724
Amplitude, sine wave, 85
Amplitude distortion, 557, 558
Amplitude modulation, 175-178
Antenna, 343-387
 Adcock, 378, 379
 aircraft, 450, 451, 472-476
 beam, 362-365
 broadcast, 635-645
 coupling units for, 189, 638-643
 current-feed, 355
 diamond, 354, 367
 dipole, 426-428
 directional, 352, 412, 413
 dummy, 449
 feed systems for, 355-357
 field patterns of, 343, 351-354, 359, 365, 369, 375
 frequency modulation, 411-413, 425-428

- Antenna, half-wave, 351, 426-428
 - Hertz, 261-262
 - high-impedance, 457
 - inverted *L*, 672, 673, 719, 720
 - lazy H, 363, 365
 - long wire, 354
 - loop, 368-372, 411, 426, 462
 - Marconi (*see* Antenna, quarter-wave)
 - measurements on, 480, 481
 - parasitic, 359
 - quarter-wave, 636, 672, 673, 719, 720
 - reactance curves of, 382
 - receiving, 366-368
 - resistance of, 645-647
 - rhombic, 354
 - ship, 655, 670, 673, 675, 719, 720
 - short wave, 350, 351, 357-359, 367
 - shunt excited, 637, 638
 - T-L, 482-486
 - top-loaded, 637
 - transmission lines, 4, 355-357, 420, 426
 - tuning of, 358, 359
 - turnstile, 360, 361, 411-413
 - vertical, 263, 351
 - very-high-frequency, 359-362, 426-428
 - voltage-feed, 355
 - Yagi, 359
- Antenna circuit, capacitance, types of, 263-272
 - classes of, 263
 - coupling to transmitting, 189, 690-691, 695
 - loop, 274-275
 - receiving,
 - complex coupling to, 272-273
 - inductive or mutual coupling to, 268-273
 - resistance coupling to, 273-274
 - tuning of, 153, 237
- Antenna coupling to transmitter, 189, 690-691, 695
- Antenna effect, 371
 - reduction of, 372-374
- Antenna impedance, 382-384
- Antenna insulator, 143, 145, 680
- Antenna measurements, 379-384, 645-647
- Antenna reactance, 382
- Antenna resistance, 379-382, 384, 645-647
- Archimedes' principle, 873
- Armature reaction, 824, 851
- Armatures, 827-829
 - troubles in, 855, 856
- Array, antenna, 352, 353, 363
- Astatic pickup, 533-534
- Atmospherics, 385
- Atoms, 3-4
- Attenuation networks, 584-591
- Audio spectrum chart, 508
- Automatic radio alarms, 754-779
 - Mackay 101A, 768-779
 - R.M.C.A. *AR*-8600, 754-768
- Automatic starters, 840-846
- Automatic temperature control, 160-162
- Automatic volume control (*AVC*), 230-235, 461
- Autotransformer, 144-146, 622
- Aviation radio receiver, marker beacon, 463-472
 - range beacon, 458-463
 - transport aircraft, 454-458
- Aviation radio transmitter, 430-453
 - care and maintenance of, 437-439, 446-448
 - ground station, 430-439
 - marine radiotelegraph service (*P.A.A.*), 452-454
 - transport aircraft, 440-451

B

- B-H curves, 57-59
- Balance circuits, 123-127
- Balance converters, 360
- Balanced-to-ground equipment, 546-547
- Band-pass filter, 240-245
- Band width, 170-171
 - required for FM, 396, 409
- Barkhausen-Kurz oscillator, 198
- Batteries (*see* Cells; Storage batteries)
- Beam antenna, 362-365
- Beam power tube, 208, 648
- Bearings, machine, 853-855
 - radio (*see* Direction finder)
- Bellini-Tosi D/F, 376-378
- Beverage on field intensity, 409
- Biasing (*see* Grid-biasing)
- Bilateral characteristic, 368-369
- Bimorph element, 524-526, 533-534
- Bleeder resistance, 321-327
- Bonding, 478-479
- Booster transformer, 63
- Bridge circuits, 126, 127

Bridge type rectifier, 304-305
 Broad tuning, 119, 237-238, 421
 Broadcast antennas, 635-645
 Broadcast control room, 542-591
 Broadcast equipment, 500-647
 Broadcast studio, 500-541
 Broadcast transmitters, amplitude modulation, 592-647
 frequency modulation, 402-405
 Brushes, 830
 lag or lead of, 825
 sparking of, 824
 troubles with, 853
 Buffer amplifier, 162-163, 691
 By-passing condenser, efficiency of, 135

C

CW (see Continuous waves)
 Capacitance, 77-84
 Capacitive coupling, 189, 264-268
 Capacitive reactance, 90-92
 Capacity, of a cell, 35
 electrostatic, 77-84
 measurements, 82-84
 specific inductive, 79
 Carbon microphone, 40-41, 517-521
 Cardioid characteristic, 375-376
 Cathode, directly heated filament, 105-107, 114-115
 indirectly heated, 115
 Cathode-ray tube, 276-285
 modulation indicator, 633-635
 Cell connections, 35-36
 Cells, capacity of, 35, 875, 894
 chemical action in, 31-33, 871-872, 892
 connection of, 35-36
 Edison, 890-894
 electrolyte in, 32, 867-869, 891-892
 internal resistance of, 36-37
 lead-acid, 864-890
 primary, 31-35
 secondary, 863-905
 temperature of, operating, 883
 voltage of, 34-35, 875
 (See also Storage batteries)
 Characteristic curve, dynamic, 181
 static, 180
 Characteristic impedance, 355
 Charged bodies, 2-6
 Chargers, filament battery, 748-751, 774

Charging panels, 894-905
 lifeboat, 899, 900
 receiver battery, 748, 750, 751, 898
 Tungar, 903-905
 Charging storage batteries, 876-878, 880-883, 893-905
 effect of polarity in, 884, 885, 895
 excessive, effect of, 889
 Charts, inductance, 75
 useful radio-frequency spectrum, 151
 Chloride accumulator (see Storage batteries)
 Choke coils, 134-136, 144-146, 319-321
 Chopper, 650-651
 Circuit (see Electric circuits)
 Circuit breaker, 857-859
 Coast stations, 720-721
 Coastal-harbor radio telephone equipment, 701-713
 Code, International Radio (*Back end paper*)
 Coercive force, 59
 Coil form, 144, 145
 Commutating poles, 825, 826
 Commutation, 821-824
 Commutator, 821-825, 833, 834
 Compass, radio (see Direction finder)
 Compensating fields, 826
 Compensating loops, 785
 Components, radio and power circuit, 143-147
 Condenser(s), 77-84
 action of, in circuit, 77, 78
 capacity of, 82
 electrolytic, 145, 146
 energy in, 80
 mica, 144, 145
 paper, 144, 145
 parallel, 80
 protective, 856
 series, 80
 variable air, 145, 146
 Conductance, 28, 95-97
 mutual, 113
 Conduction, electrical, 6-8
 Conductivity, 11, 12
 Continuous waves, 137, 138
 converting phone to (*CW*), 439, 440
 (See also A1 emission)
 Control grid, 109
 Control room equipment, 542-591
 Conventional current flow, 31

Copper losses, 63
 Copper oxide rectifiers, 311, 312
 Core losses, 63
 Coulomb, 10-11, 78
 law of, 6
 Counter e.m.f., 69, 834
 Counterpoise, 365-366
 Coupled circuits, 237-240
 Coupling, capacitive, 189, 264-268
 complex, 272
 impedance, 218-219
 inductive, 70-71
 magnetic, 70-77
 mutual, 76-77, 239, 268-271
 Coupling coefficient, 77, 240
 Coupling unit, 189, 638-643
 Cross talk, 542-544
 Crystal filter, 253-255, 259
 Crystal oscillator, 157-162
 Crystal resonator, 158, 159
 Current, 7-10
 alternating, 60-62, 84-88
 effective, 88
 Current-feed antenna, 355
 Current flow, 31, 33-34, 107, 300
 Current-square ammeter, 337
 Current transformation, 65
 Cycle, 62, 84

D

D'Arsonval movement, 330-332
 Day and night effects, 386
 Decibel (db), 509-515
 problems, 510-515
 ratio table, 510
 reference level for zero, 512
 Deemphasizer, 408
 Delta connection, 101-102
 Delta-delta connection, 307
 Delta-star connection, 307
 Demodulator, 208
 Detection, 208-213
 crystal-detector, 751-752
 diode, 229, 230
 operation of square law, 776
 regenerative, 245-247
 Deviation, 374, 785-786
 Diamagnetic material, 46
 Dielectric constants, 79
 Dielectrics, 79

Diode, 105, 229-230, 419
 operating characteristics, 107-109
 Dipoles (*see* Antennas, half-wave)
 Direct-current electricity, 1-54
 Direct-current meters, 330-334
 Direction finder, Adcock system, 378,
 379, 483, 484
 applications of marine, 780, 781
 aviation, 489-499
 Bellini-Tosi system, 376-378
 bilateral characteristic, 368, 369
 calibration of, 809-812
 cardioid characteristic, 375, 376
 deviation of, 374, 785, 786
 elements of, apparatus, 781-784
 fixing position by, 814-816
 fundamental principles of, 368-379
 grounding and shielding, 784
 Mackay Model 105-A, 795-806
 maintenance of, 816, 817
 marine aircraft radio, 806-808, 811,
 816, 817
 marine ship radio, 780-817
 operation of, 812-814
 Pan American Airways, 808
 R.M.C.A. Model AR-8703-B, 787-795
 signal indication on, 784, 785
 Sperry automatic, 493-499
 troubles and remedies, 817
 unilateral characteristic, 375, 376
 Discharge (battery) rate, 875, 876
 Discriminator, 390, 406, 413, 416-420
 adjustment of, 425
 alignment of, 424
 Distortion, 500
 amplifier, 190-192, 219-221, 224
 amplitude, 557-558
 measurement of, 282
 Doherty amplifier, 183-188, 627-628
 Double antenna, 351
 (*See also* Antenna, dipole)
 Dynamo (*see* Generator)
 Dynamotor, 850-851
 Dynatron oscillator, 142-143

E

E layer, 345
 Eddy currents, 63
 Edison effect, 107
 Edison storage battery, 890-894

Electric charges, 1-3
 current, 7
 Electric circuits, 14-20, 35, 36
 complex problems, 37-38
 parallel, 16, 36
 series, 15, 35
 series-parallel, 17, 36
 Electric field, 3, 49-52, 77-78, 343
 Electrical transcription, 528-541
 Electrolyte, Edison cell, 891-892
 lead-acid cell, 867-869
 Electromagnetic fields (*see* Magnetic fields)
 Electromagnetic induction, 52-54
 Electromagnetism, 49-51
 Electromotive force (e.m.f.), 8-10
 absolute unit of, 29
 by chemical action, 31-33
 formula, 87
 by mechanical action, 53, 54, 60-62
 Electron, 3-4
 flow of, in gas, 300
 in liquids, 32-33
 free, 6-8
 velocity of, 7
 Electron gun, 276
 Electron mass, 3
 theory, 1
 Electronic power supplies, 293-342
 Electroscopes, 2
 Electrostatic capacity, 77-84
 Electrostatic field, 3, 49-52, 77-78, 343
 Electrostatic units, 3
 Emergency transmitter, 669-672
 Emission, electron, 106-107
 wave (A_1 , A_2), 650-653, 684, 686-687, 720
 Energy, 28, 29
 Equalizers, 581-583
 Equalizing resistance, 321-322
 Ergs, 29
 Ether, 343-344
 Expansion systems, 536-537
 Exponential horn, 292

F

F-layer, 345
 Fading, 385-386
 Fading circle, 349
 Farad, 78

Feedback, acoustical, 555
 regenerative, 245-247
 stabilized, 183-188, 627-628
 Ferraris principle, 400
 Ferromagnetic material, 46
 Field coils, 856
 Field excitation, generator, 829-830
 Field strength, measurements of, 347-350, 410
 Filament current, effect of, 108
 Filaments, 105-106
 alternating-current operation of, 113-115
 power supply for, 190
 series connection of, 20
 Filter(s), band-pass, 240, 241
 band-elimination, 240-242
 comparison of, 328
 high-pass, 240-241
 interference, 387, 753
 low-pass, 240-241, 314-316
 plate and grid, 116, 561-562
 power-supply, 313-321
 scratch, 530
 Filter choke, 144, 145, 146
 Filter condensers, 316-319
 Flux lines, 44-45, 54
 Flywheel effect, 70, 122
 Force, 1-6, 28
 Frequency, 62
 formulas for, 86
 relations of, in transformer, 67
 Frequency control, 597-598
 Frequency-divider circuit, 404, 407
 Frequency indicator, 339-340
 Frequency meter, 286-289
 Frequency modulation, 388-429
 AM compared with, 389-391
 AM receiver compared to receiver for, 413-414
 Armstrong method of, 399-402
 band width for, 396, 409, 421
 center frequency in, 392
 deviation ratio in, 395
 practical considerations of, 405-408
 propagation of, waves, 409-411
 r-f circuits in receivers for, 420-422
 receiver for, 413-414, 429
 receiving antenna for, 425-428
 servicing of receivers for, 422
 skip distance effect on, 390-391
 systems of, 396, 402

- Frequency modulation, theory of, 392-396
 transmitting antennas for, 411-413
 Western Electric transmitter for, 402-405
- Frequency monitor, 188, 598, 628-632
- Frequency multipliers, 165-167
- Frequency response curves, 119
- Frequency runs, 583-584
- Frequency-selection circuits, 444
- Frequency spectrum, useful radio, 148, 151
- Frequency stability, 406, 598
- Fuses, 329, 696, 856-857
- G**
- Gain, calculation of, 119-120, 264, 266-267, 269, 271-274
- Gain control, 562-563
- Galvanometer (*see* D'Arsonval movement)
- Gamma rays, 4
- Gauss, 56
- Generation (*see* Electromotive force)
- Generator, alternating-current (*see* Alternators)
- Generator, direct-current, 821-832
 double-commutator, 826-827
 double current, 852
 types and uses, 831
 voltage control on, 830-831
- German silver, 11
- Gilbert, 55
- Goniometer, radio, 376
- Grid biasing, 109-110
 effects of, in amplifiers, 121-123
 methods of, 132-134
- Grid excitation, 178-183
- Grid filter, 228-229
- Grid leak, 211
- Grid modulation, 171-173
- Ground connection, 365, 450, 636, 784
- Ground waves, 344-345
- Guided waves, 359-360
- H**
- HRO receiver, 255-261
- Hand rules, 51-52, 54
- Harmonic distortion, 557-560
- Harmonic producers, 165-167
- Harmonics, causes of, 190-192, 557-560
 musical, 558
 suppression of, 192-194, 649
- Hazeltine balance (neutralization), 124-125
- Headphones, 38-40
 aviation special, 472
- Heating in electrical circuits, 29-30, 63, 293
- Heaviside layer, 344-347, 390, 479
- Heising modulation, 171, 173-176
- Helium atom, 4
- Henry, 72
- Hertz antenna, 261-262
- Heterodyne reception of *CW*, 251-252
- High impedance input, 421
- Hot-wire ammeter, 336-338
- Hum, 113-116, 564
- Hydrogen atom, 4
- Hydrometer, 873-875
- Hysteresis, 58-59, 63
- I**
- ICW*, production of, 650-653
- IR* drop, 15
- Image frequency, 251, 422
- Impedance, 89
 surge, 357
- Impedance-inverting networks, 184-186
- Impedance matching, 356
 (*See also* Load matching)
- Induced currents, 52
- Inductance, 67-77
 calculations, 72-77
 physical structure of, 144-146
- Induction, 67-71
- Induction motor, 838-839
 starting the, 846-847
- Inductive reactance, 89-90
- Inductor alternator, 819-820
- Inductors, transmitting, 144-145
- Inertia (*see* Flywheel effect)
- Input impedance, 117
- Insertion loss, 552-553
- Instantaneous recording, 537-541
- Insulators, 143, 145-146
- Interference, man-made, 387
 discrimination against, by FM, 388, 411, 428
 other station, 386

Internal drop, 15
 Internal resistance, 32, 36-37
 International Radio Code (*Back end paper*)
 Interpole machines, 825-826, 836
 Inverse-distance curve, 347
 Inverse-peak voltage, 301-302
 Inverse-square law, 6
 Ionization, 32-33, 300
 Ions, 32-33, 300
 Isolantite, 698
 Isolation circuits, 242

J

Jack circuits, 563
 Joule, 29, 82
 Junction rectifiers, 311-313

K

Kelvin temperature, 11
 Kennelly-Heaviside layer, 344-347, 390, 479
 Key, standard radiotelegraph, 753
 Keying methods, 439-440, 649-650, 687
 Kilovolt-ampere, 100
 Kinetic energy, 89
 Kirchhoff's laws, 22-28

L

Ladder networks, 550
 Lap-winding, 827-828
 Lateral cut recording, 529
 Law(s), induction, 52
 inverse square, 6
 Kirchhoff's, 22-28
 Lenz's, 52, 70
 Ohm's, 12-14
 for alternating-current circuits, 93
 for magnetic circuits, 55
 shunt, 21
 Lead-acid cell, 864-890
 Left-hand rules, 51-52, 54
 Lenz's law, 52, 70
 Lifeboat radio, 672-683
 Limiter, 390, 413-416
 Limiting amplifier, 545
 Line-of-sight distance, 349-350
 principle of, applied to FM, 409
 Lissajous figures, 281-282
 Load matching, 30-31, 110

Local action, 34
 Logarithms, 507-510
 tables, 911-913
 Log entries, 765
 Loop antenna, 274-275, 368-372, 781-783
 (*See also* Direction finder)
 Loud-speakers, 289-292, 753
 Low-pass filters, 240-241, 314-316

M

M.O.P.A. transmitters, 151-153, 452-454
 (*See also* Marine radio transmitters)
 Magnesium-copper sulphide rectifier, 312, 313
 Magnetic circuit, 54-57
 Magnetic fields, 43, 44, 343, 344
 around conductor, 49-52
 effect on compass needle, 50
 rules for direction of, 51, 52
 Magnetic leakage, 44
 Magnetic materials, 55
 Magnetic poles, 42, 43
 Magnetism, 41-48, 54-59
 Magnetomotive force, 54
 Magnetostriction effects, 46, 48
 Marine radio receivers, 722-753
 coastal-harbor, 703-713
 high-frequency, 740-747
 low-frequency, 727, 732
 medium-frequency, 675, 680, 682, 727, 732, 738, 751-752
 very low frequency, 727, 732
 (*See also* Receivers)
 Marine radio transmitters, 648-721
 care and maintenance of, 714
 coastal-harbor radiotelephone, 701-713
 complete ship station utilizing, 713
 high-frequency, 683-701
 medium-frequency, 653-683
 troubles in, 700, 714-719
 (*See also* Transmitters)
 Marker beacon, 488
 Master control system, 547
 Materials, conductivity of, 11, 12
 insulating, 2
 (*See also* Dielectrics)
 magnetic, 55
 non-magnetic, 55
 Matter, 3
 Maximum peak inverse voltage, 298-299
 302, 321

- Maximum peak plate current, 298-299, 321
- Mesh connection (*see* Delta connection)
- Meter amperes, 636
- Meters, 189-190, 201, 330-342
VU, 580-581
- Microphone, 38-40, 515-528
carbon, 38-40, 517-519
condenser, 519-521
crystal, 524-526
directional, 526-527
dynamic, 521-522
lapel, 527
machine-gun, 528
parabolic, 527-528
placement of, 504-507
ribbon, 522-524
velocity, 522-524
- Mirophone amplifier, 520
- Microphonic tube, 555
- Mixer, 545, 547-554
tube (*see* Pentagrid converter)
- Modulated amplifier, 172-178
- Modulation, 167-169
constant-current, 171-176
frequency, 388-429
(*See also* Frequency modulation)
grid bias, 171-173
Heising, 171-176
high-level, 171, 594
low-level, 171, 594
measurement of, 282-283, 632-635
plate, 171-176
below ten meters, 199-201
- Modulation factor, 169
- Modulation percentage, 169, 393
- Modulator, code, 652, 653
(*See also* Modulated amplifier)
- Monitor amplifier, audio-frequency, 188, 578
radio-frequency, 188, 628-632
- Motor generator, 838, 850-855
- Motors, alternating-current, 837-839
direct-current, 832-837
induction, 838, 839
maintenance of, 852, 853
operation of, 849, 850
synchronous, 837
trouble shooting, 855, 856
universal alternating- and direct-current, 836
- Multigrid tubes, 203-208
characteristic curve, 205
pentagrid converter (mixer), 250, 251, 707, 710
- Multiple reception, 725
- Multiplier for voltmeter, 331, 332
- Musical spectrum chart, 508
- Mutual induction, 70-77
- Mycalex, 698

N

- Nagaoka's inductance formula, 73-76
- Negative resistance, 246
- NEMO mixing, 553, 554
- Neutralization, 123-127, 615
- Neutron, 4
- Nickel-iron-alkaline cell, 890-894
- Night effect, 371, 372, 479, 481
- Noise (*see* Interference; Static)
- Noise-suppression circuit, 235, 236
in amplifiers, 550-552
antenna system for, 366
(*See also* Crystal filter; Filters, interference)
- Non-magnetic materials, 55

O

- Oersted, 52
- Ohmmeter, 340-342
- Ohm's law, 12-14, 55, 93
- Open oscillatory circuit, 343
- Oscillation, overcoming (*see* Balance circuits; Neutralization)
- Oscillator, Armstrong, 670
audio, for A2 emission, 651, 652
Barkhausen-Kurz, 198
for below 10 meters, 196-199
broadcast transmitter, 599-602
Colpitts, 139
dynatron, 142, 143
electron, 198, 199
electron-coupled, 140-142
fundamental, 137, 138
Gill-Morrell, 198
Gutton-Touly, 196
Hartley, 138, 139, 152
Mesney balanced, 196
parallel-feed, 155
push-pull, 139
series-feed, 154

Oscillator, as a transmitter, 150
 tuned-plate, tuned-grid, 143
Oscillograph, cathode-ray, 276-285
Overload circuit breaker, 857-859
Overmodulation, 283

P

Pads, 549, 550, 584-591
Parallel circuit, 16, 17
 alternating current, 95-97
Parallel feed, in oscillator, 138, 155
Parallel resonance, 98, 99, 236-240
Paramagnetic material, 46
Parasitic oscillations, 194, 195
Parasitic radiator, 359
Peak factor of alternating current, 88
Peak voltmeter, 632, 633
Pentagrid converter (mixer), 250, 251,
 707, 710
Pentode, 205-208
Permalloy, 57
Permeability, 58
Phase angle, 84, 92
Phase monitors, 643-645
Phase relations, 88-95
Phase-shifting networks, 184-186, 403,
 404
Phone transmission (*see* Transmitters)
Photons, 4
Pi-network, 357
Pickup equalization, 535, 536
Pickup heads, 529-535
Pickup mixing, 553, 554
Piezo-electric crystal (*see* Crystal oscillator)
Plate component, alternating current,
 135, 227
Plate filter, 134-136, 228, 229
Plate potential, effect of, 107
 source of, 190
Plate resistance, 113
Polarization, 32
 of antenna field, 343, 366
 of FM wave and antennas, 411, 427
Pole pieces, 47
Polyphase circuits, 101-104
Positive resistance, 245
Positron, 4
Potential, 5, 6
Power, 28-29, 99-100, 104
 maximum rated carrier, 594
 operating, 595-597

Power amplifier, 164-165, 178, 221-223
 distortion in (*see* Harmonic distortion)
 Doherty high-efficiency, 183-188
 efficiency of, 188
 grid excitation for, 178-183
 load calculations for, 176-178, 221-222,
 639-641
 tubes for, 205-207
Power factor, 92
Power output, of push-pull amplifier, 227
 vacuum tube, 221-223
Power supplies, 190, 293-330, 686, 724
 (*See also* Motor generator; Storage
 batteries)
Preamplifier, 520
Preemphasis, 401, 408
Production men, duties of, 505, 506
Protective devices, 296, 725, 856-859
 (*See also* Circuit breakers; Fuses;
 Relays)
Protons, 3, 4
Push-pull amplification, 223-228
Push-pull balance circuit, 126

Q

Q, circuit, 155, 156, 264-275
Quartz plate (*see* Crystal)

R

R.M.S. (root-mean-square) value, 88
RST scale, 260
Radian, 392
Radiation field, 343, 344
Radiation lobes (*see* Antenna field
 patterns)
Radiation resistance, 645-647
Radiating systems (*see* Antenna)
Radio aids to navigation (*see* Direction
 finders)
Radio beacons, marine, 780, 781
 (*See also* Radio range systems)
Radio compass (*see* Direction finder)
Radio-frequency amplifiers, 116-122,
 602-618
 voltage, 262-275
 (*See also* Power amplifier)
Radio-frequency chokes, 134-136, 144-
 146, 153
Radio-frequency shielding, 127-129
Radio goniometer, 376-378

- Radio-range, systems, 479-488
 - receiver, 458-463
- Radio spectrum, useful, 148
 - chart of, 151
- Radiotelephone transmitter, block diagram, 149, 593
- Reactance, 89-91
 - magnetic leakage, 65
- Reactance tube system of FM, 398
- Reactor, 320
- Receivers, aviation, *W.E. Type 25C*, 458-463
 - W.E. Type 27B*, 463-472
 - W.E. Type 29A*, 454-458
- beacon, 458-463
- crystal detector, 751, 752
- emergency, 738-740
- HRO*, 255-261
- main, 726-737
- marine *RMCA, Type AR-8503*, 727-731
 - Type AR-8505*, 740-747, 750
 - Type B*, 752
- marine *Mackay, Model 117B*, 732-737
 - Model 122A & B*, 738-740
 - Model 123*, 752
- regenerative, 245-247
- superheterodyne, 247-261, 788
- troubles with, 725, 726
- tuned radio-frequency, 231, 732-737, 798-800
- very-high-frequency, 262
 - superheterodyne, 463-472
 - superregenerative, 247
- (See also Marine radio receivers)
- Receiving circuit principles, 203-275
- Reception, methods of, 236-255
- Recording, 528-541
- Rectification, 106, 107
 - (See also, Detection; Rectifiers)
- Rectifier, 297-313
 - bridge type, 304, 305
 - copper-oxide, 311, 312, 404
 - full-wave, 303-305
 - half-wave, 300, 301, 904
 - junction, 311-313
 - magnesium-copper-sulphide, 312, 313
 - mercury-vapor, 299-301
 - single-phase, 303-306
 - signal (see Detection)
 - theory of, 297, 298
 - three-phase, 306-311
- Rectifier, Tungar, 903-905
 - types of, 327
 - voltage doubling, 305, 306
- Rectifier losses, 328
- Rectifier troubles, 329, 330
- Rectifier tubes, high-vacuum type, 298
 - mercury-vapor type, 299-301
- Recycling circuit, 619
- Reflected resistance, 177, 239
- Regenerative receiver, 245-247
- Regulation, 831, 832
 - improvement of, 321
- Rejector circuits, 244, 245
- Relaxation oscillator, 278
- Relay, operation of, 433-437, 448, 621-625
 - overload, 620
 - reverse-current, 902
 - time delay, 622
- Reluctance, 55, 58
- Reluctivity (see Reluctance)
- Remanence, 58
- Remote control, 571-578
- Reproducer (see Headphones; Loud-speakers)
- Residual magnetism, 58
- Residual signal, 370
- Resistance, 11
 - of alloys, 11
 - of electrolytes, 12
 - measurement of, 341, 342
 - negative, 246
 - plate, 113
 - positive, 245
 - reflected, 177, 239
 - relative, of conductors, 12
 - table, 12
- (See also Inside back cover)
- Resistor, 143-145
 - static drain, 385
- Resonance, 97-99, 236-240
- Resonance curve, 265
- Resonator, crystal, 157-159
 - mechanical, 156, 157
- Retardation coil, 320
- Retentivity, 58
- Reverberation, 501
- Rheostat, field, 830, 835
 - power, 144, 145
- Rice balance circuit, 126
- Ripple frequency, 327, 328
- Ripple filters, 313-321, 860-862

Rochelle-salts crystal, 524-526
 Rotary converter, 851
 Rotor, 820, 837, 838
 Rules, left-hand, 51, 52, 54
 right-hand, 833

S

S meter, 259-261
 Sabine formula, 501
 Saturation, magnetic, 58, 293, 294
 tube, 107
 Saturation point, 107
 Saw-tooth oscillator, 278
 Saw-tooth voltage, 278
 Scratch filters, 530
 Screen grid tube, 203-205
 Seasonal effects, 386
 Second-harmonic frequency, 225
 Secondary cells (*see* Storage batteries)
 Secondary emission, 143, 206
 Selective circuits, 236-239
 Selectivity, 119, 265, 267, 271, 742, 743
 Selector (*see* Automatic radio alarms)
 Self-induction, 68-70
 Sense characteristic, 374-376, 492
 Sensitivity, auto alarm, 769
 FM receiver, 421
 high-frequency receiver, 742
 marker-beacon receiver, 469
 Sensitivity control, 756, 758, 763, 767,
 770
 (*See also* Fig. 15-3)
 Series circuit, 15, 16, 18
 alternating-current, 93-95
 Series feed, in oscillator, 138, 154, 159
 Series-parallel circuit, 17, 36-38
 Series resonance, 97, 98, 236-240
 Service area, 349
 Servicing FM receivers, 422-425
 Sharp tuning, 119, 237
 Shielding, 127-132, 477, 556, 784
 Ship antennas, 655, 670, 673, 675, 719-
 720
 Ship radio station, complete, 713
 Shot effect, 555
 Shunt, ammeter, 332-334
 Shunt law, 21, 22
 Side bands, 169-171, 238
 Signal-to-noise ratio, 385, 470
 Sine wave, 84-85
 Single-signal receiver, 252-255

Sinusoidal wave(s), 85
 addition of, 252
 Skip distance, 345-347
 Sky waves, 344, 345
 Slope filter, 413
 Sound, 507
 Space charge, 106-108, 300
 Space quadrature, 343
 Specific gravity, 873-875
 Specific inductive capacity, 79
 Specific resistance table, 12
 Speech amplifiers, 545, 546
 Speech input equipment, 565-571
 Speed control, motor, 847-849
 Square-wave generator, uses in FM, 408
 Standing waves, 358
 Star connection, 101-104, 306, 307
 Star-delta connection, 306, 307
 Starting box, 839, 840
 Statcoulombs, 3, 5
 Static, 385
 Stator, 820, 837
 Storage batteries, 863-905
 care of, 662, 663, 677-679, 887-889
 comparison of lead-acid and Edison,
 894
 emergency, broadcast, 879
 marine, 870, 878, 879
 ventilation of, 884, 894
 voltage check on, 672, 683
 (*See also* Cells)
 Stray fields, 550-552, 554-557
 Strength-of-signal scale, 260
 Studio, broadcast, 502-504
 Sulphation, 885-887
 Superheterodyne receiver, 247-261, 788
 image frequency in, 251
 ultra-high-frequency, 262
 (*See also* Marine radio receivers)
 Superregenerative receiver, 247
 Suppressor grid, 205, 208
 Surge impedance, 357
 Susceptance, 95
 Sweep voltage, 278
 oscillator, 278
 Swinging choke, 321
 Switches, 857
 antenna, 762, 773, 774
 gate, 436, 437
 power-transfer, 753
 Synchronous condenser, 837
 Synchronous motor, 837

T

Tables:

- IA, Relative Conductances and Resistances of Conductors, 12
- IIA, Value of K for Nagaoka's Inductance Formula, 74
- IIB, Specific Inductive Capacities, 79
- IVA, Useful Radio Spectrum, 148
- VIIA, Approximate Skip Distances, 346
- XA, Relationship of Power Ratios to Decibels, 510
- XIA, Relative Strength of Prime Note and Harmonic Components, 558
- XIB, The Constants X^K and Y^K for H and T Pad Computations, 587
- XIIA, Factor F for Calculating Operating Power, 596
- XIIB, Vacuum Tubes Required for Broadcast Transmitter, 620
- XIIC, Typical Meter Readings on Broadcast Transmitter, 621
- XIIIA, Troubles in Vacuum Tube Transmitters, 715
- XIVA, Troubles in Radio Receivers, 725
- A, B , Wave-length-frequency Conversion, 907-910
- Logarithmic Tables, 911-913
- Wire Table (*Inside back cover*)
- Telephone lines for broadcasting, 408, 584, 593
- Telephone receiver(s), 38-40
 - high-impedance, 262
 - (*See also* Headphones)
- Telephone system, 39, 41
- Telephone transmitter (*see* Carbon microphone)
- Temperature-control chamber, 160-162
- Temperature correction in batteries, 874
- Test buzzer, 758
- Thermocouple ammeter, 337, 338
- Thévenin's theorem, 263, 266, 268
- Three-phase system, 101-104
- Time-delay circuit, 619, 622
- Torque, 834
- Transconductance, 113
- Transformer, 62-67
 - audio, 144-146, 723
 - connections, 295, 307
 - electrostatically shielded, 296
 - Transformer, filament, 144-146
 - interstage, 144-146
 - matching, 216-217
 - physical structure, air core, 144-145
 - iron-core, 64
 - power, 144-145, 293-297
 - voltage regulating, 295
 - Transformer-coupled audio amplifier, 215-216
- Transmission lines, 355-357, 361, 612-613
 - coupling circuits for, 638-643
- Transmitter care and maintenance, 714
- Transmitter rating, 594, 595
- Transmitter troubles, 438, 448-449, 714-719
- Transmitters, crystal-controlled, 153
 - for below ten meters, 199-202
 - Aviation: *P.A.A.*, (radiotelegraph) 452-454
 - W.E. Type 14C*, 430-439
 - W.E. Type 27A*, 440-451
 - Broadcast: (FM) *W.E. Type 503A-1*, 402-405
 - (AM) *W.E. Type 12A*, 621-624
 - W.E. Type 405B-2*, 625-628
 - W.E. Type 442A-1*, 598-620
 - Marine, *RM.C.A.*, *Type EJ-8007*, 672-679
 - Type ET-8010-C*, 653-663
 - Type ET-8012-B*, 701-713
 - Type ET-8019*, 683-692
 - Marine, *Mackay*, *Type 101-A*, 679-683
 - Type 109*, 663-669
 - Type 131-A*, 669-672
 - Type 136-A*, 692-701
 - (*See also* Marine radio transmitters)
- Transmitting-circuit principles, 148-202
- Trap circuits, 244-245
- Triode, 105-110
 - amplification factor of, 111-113
 - characteristic curve of, 180, 181
 - mutual conductance of, 113
 - plate resistance of, 113
- Troubles, direction finder, 817
 - generator, 852-856
 - motor, 852-856
 - receiver, 725, 726
 - rectifier, 329, 330
 - storage battery, 889
 - transmitter, 438, 448, 449, 714-719
- Tube (*see* Vacuum tube)
- Tube harmonics, 558-560

Tuned circuits, 236-245
 (See also Resonance)
 Tungar charger, 903-905
 Tuning, broadcast transmitter, 605-621
 marine D/F, 789
 marine transmitter, 658-660, 667, 668,
 687-692, 696-701, 705-707
 receiver, 237-240, 470-471, 730, 733
 Tuning key, 691

U

Units, current, 10
 e.m.f., 9
 electrostatic, 3, 78
 energy, 29
 inductance, 72
 power, 29
 resistance, 12
 transmission, 509, 580

V

Vacuum contact relay, 859, 860
 Vacuum tube(s), alternating-current
 operated, 113-116
 beam power, 208, 648
 care of, 437, 438, 446, 447
 grid-controlled gas, 278
 heater type, 115, 116
 metal, 147
 pentode, 205-208
 screen-grid, 203-205, 208
 super control, 203-205, 208
 theory of, 105-110
 transmitting type, 145, 146
 triode, 105
 variable- μ , 204
 Vacuum-tube characteristics, 110
 Vacuum-tube oscillators, 137-143
 (See also Oscillators)
 Vacuum-tube socket, 144, 145
 Vacuum-tube voltmeter, 632, 633
 Vectors, 84, 85, 88-95, 102, 103
 Vertical cut recording, 529
 Volt(s), 9
 absolute unit of, 29
 per meter, 348

Volt-amperes (VA, KVA), 100, 639
 Voltage, effective, 64, 87, 88
 inverse peak, 301, 302
 r.m.s. value, 88
 storage battery, 875, 894
 (See also Electromotive force)
 Voltage amplifier, 117, 163-165, 262-275
 Voltage check on battery, 672
 Voltage divider, 323-327
 Voltage-feed antenna, 355
 Voltage-regulating transformer, 295-296
 Voltage regulation, 321, 831, 832
 Voltage regulator, 620, 760
 (See also Rheostat)
 Voltage transformation, 63, 65-66
 Voltmeter, 330-332, 334-336
 vacuum-tube, 632-633
 Volume control, 530
 automatic, 230-235, 461
 Volume indicator, 578-581
 VU meter, 580-581

W

Watt, 29
 Wattmeter, 339
 (See also Ampere-hour meter)
 Watt-seconds, 29
 Wave length, 344, 384
 conversion of, to frequency, 907-910
 Wave meter, 286-289
 Wave propagation, 343-347, 390-391,
 409-411
 Wave traps, 244-245
 Wave winding, 827, 828
 Waves, electric, 343-347
 sinusoidal, 85
 velocity of, 344, 364
 Wire table (*Inside back cover*)
 Work, 28

Y

Y connection, 101, 306

Z

Zero reference level, 512

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STANDARD ANNEALED COPPER WIRE SOLID

Wire Gage (B. & S.) English Units

Wire Gage (B. & S.)	Ohms per 1,000 ft.		Ohms per mile 25° C. (77° F.)	Pounds per 1,000 ft.	Current- carrying capacity. ¹ Insula- tion ^{2,3}
	25° C. (77° F.)	65° C. (140° F.)			
22	0.0500	0.0577	0.264	641.0	225
20	0.0630	0.0727	0.333	508.0	175
18	0.0795	0.0917	0.420	403.0	150
16	0.100	0.166	0.528	319.0	125
14	0.126	0.146	0.665	253.0	100
12	0.159	0.184	0.839	201.0	90
10	0.201	0.232	1.061	159.0	80
9	0.253	0.292	1.335	126.0	70
8	0.319	0.369	1.685	100.0	55
6	0.403	0.465	2.13	79.5	50
4	0.508	0.586	2.68	63.0	35
3	0.641	0.739	3.38	50.0	35
2	0.808	0.932	4.27	39.6	25
1	1.02	1.18	5.38	31.4	25
0	1.28	1.48	6.75	24.9	20
-1	1.62	1.87	8.55	19.8	20
-2	2.04	2.36	10.77	15.7	15
-3	2.58	2.97	13.62	12.4	15
-4	3.25	3.75	17.16	9.86	
-5	4.09	4.73	21.6	7.82	
-6	5.16	5.96	27.2	6.20	
-7	6.51	7.51	34.4	4.92	
-8	8.21	9.48	43.3	3.90	
-9	10.4	11.9	54.9	3.09	
-10	13.1	15.1	69.1	2.45	
-11	16.5	19.0	87.1	1.94	
-12	20.8	24.0	109.8	1.54	
-13	26.2	30.2	138.3	1.22	
-14	33.0	38.1	174.1	0.970	
-15	41.6	48.0	220.0	0.769	
-16	52.5	60.6	277.0	0.610	
-17	66.2	76.4	350.0	0.484	
-18	83.4	96.3	440.0	0.384	
-19	105.0	121.0	554.0	0.304	

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PUNCTUATION AND SPECIAL SIGNALS

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Go Ahead (k).....	■■■ • ■■■
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End of Message (cross x).....	• ■■■ • ■■■ •
Transmission Finished (sk).....	• • • ■■■ • ■■■

Note.—For complete information and course on radio code the reader is referred to the *Radio Code Manual* by A. R. Nilson, McGraw-Hill Book Company, Inc., New York.

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